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ANALYSIS AND EVALUATION OF SELECTED PACE APPLICATIONS

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FINAL REPORT

(Task 4)

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16. ABSTRACT

Selected applications of the Omega System Availability model are analyzed and compared. These applications illustrate the range and scope of issues which may be addressed by the System Availability model. Three general applications at the primary Omega frequency of 10.2 kHz are described in terms of scenarios which postulate specific system conditions or configurations. These applications make use of the PACE workstation which incorporates the new 24-hour/4-month/2-frequency signal coverage database. The applications analyzed in this report include: (1) comparison of system availability using the previous (2-hour/4month/2-frequency) and new signal coverage databases, (2) comparison of global and regional system availability and the sensitivity of system availability to signal coverage access criteria thresholds, and (3) comparison of system availability as interpreted by conventional airborne Omega receiver/processor signal deselection algorithms and PACE with baseline signal coverage access criteria. For most of the applications, system performance is examined in terms of three system station power level configurations: (1) all transmitting stations at full power, (2) a 6 dB power reduction at the Hawaii station (all other transmitting stations at full power), (3) Hawaii permanently off-air (all other transmitting stations at full power). Comparisons of system performance are presented in terms of the diurnal behavior of the system availability index.

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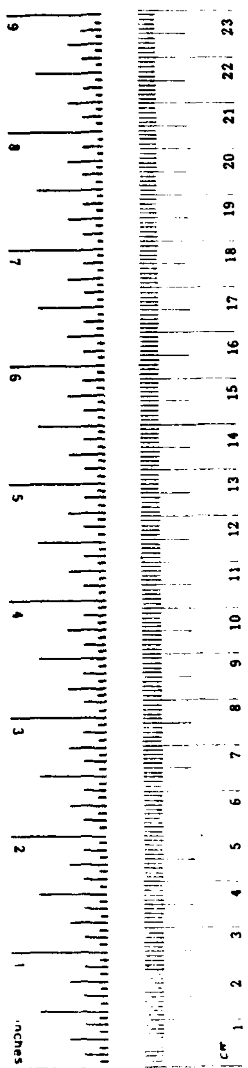
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

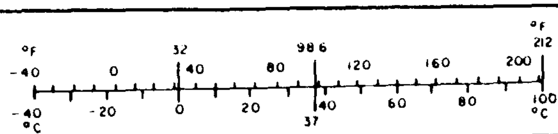
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 [illegible]



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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The author wishes to acknowledge the contribution of Mr. George Desrochers of TASC who modified the PACE software to emulate earlier system performance assessment results. Mr. Desrochers also developed special software to emulate the modal deselection algorithms used in conventional airborne Omega receivers.

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1. INTRODUCTION

The Omega System Availability Model (Ref. 1) was originally developed to evaluate the performance of the Omega System in terms of four system components:

(1) Omega receiver reliability/availability
(2) Omega transmitting station reliability/availability
(3) Omega signal usability/accessibility/coverage
(4) Omega user geographic regional priority.

The PACE (Performance Assessment and Coverage Evaluation) workstation has been developed (Ref. 2) to implement the Omega System Availability Model/Algorithm. PACE is a powerful tool for probing the multi-dimensional aspects of Omega system availability. Several applications of the System Availability Model, utilizing PACE, described in this report illustrate the range and scope of the model as applied in conjunction with PACE.

1.1 BACKGROUND

The Omega System Availability Model (and subsequently, PACE) provides a more comprehensive assessment of Omega system performance than previously obtained from station reliability or signal coverage alone. This need became especially critical in the late 1980's when estimates of antenna repair cost at several Omega stations were sufficiently high to consider extreme options, such as permanently reducing station power or station disestablishment. An accurate measure of the impact of these options on system performance was needed for crucial budget considerations and program management decisions. The Omega System Availability Model provides the appropriate measure, the system availability index (P_{SA}), and the theoretical structure for the calculation of P_{SA}. Because the P_{SA} computation is complex and many inputs/conditions can be specified, the PACE workstation was developed to assist the Omega system provider* in assessing/evaluating system options.

The initial development of the System Availability Model was conducted under an ONSCEN-sponsored effort entitled System Performance Assessment: Phase I (SPA I, Ref. 1). As

* U.S. Coast Guard Omega Navigation System Center (ONSCEN)

part of this effort, an algorithm was developed to compute P_{SA} based on available data pertaining to the system components listed above. In particular, signal coverage data (system component (3) from the list above) for SPA I were obtained from much earlier signal coverage calculations (see Ref. 3) at 10.2 kHz for two UT hours (0600 and 1800) and four coverage months (February, May, August, and November). The actual coverage data processed by the System Availability Algorithm developed under SPA I were global coverage elements, i.e., fractions of the earth's surface covered by each possible combination of stations.

The System Availability Model was further refined in a subsequent effort entitled System Performance Assessment: Phase II (SPA II) which also included design and development of PACE. PACE development coincided with development of a new signal coverage database, also a part of SPA II. In addition to correcting a number of earlier signal propagation computational problems, the new database includes many additional calculations which expand the number of global times for which the data is specified and increases the information supplied in the two space dimensions.

In changing from the earlier signal coverage information to the new signal coverage database, the number of hours for which the signal data are specified increases from two to twenty-four (the number of months (4) remains the same). This change greatly expands the utility of the signal coverage database, since, relative to the earlier time conditions, the new data specification increases the time (hour) sampling rate from under 10% to 100%, thereby:

- Providing complete diurnal information instead of just two hours (0600 and 1800 UT) which generally do not properly characterize the 24-hour day or bracket "best" and "worst" coverage of the 24-hour day
- Permitting interpolation between successive hours which was previously excluded since the earlier coverage information was specified at two times separated by 12-hour intervals.

Interpolation between successive hours and computed months is allowed because the signal parameter data contained in this new database are found to change relatively little between coverage month intervals (3 calendar months) at a fixed hour and between UT hours at a fixed month. As a result, signal coverage (and thus, P_{SA}) may be reliably specified at all times within the period of a year.

In the two spatial dimensions (latitude/longitude), the new signal coverage database provides data at *all* points on the globe* rather than just the spatial point at which one or more signal

* The spatial unit is the *cell* with an area of approximately one square megameter so that 444 cells cover the globe.

parameter thresholds (e.g., an SNR of –20 dB) occur, as did earlier coverage information products. This "matrix- based" approach to spatial coverage specification not only provides much more data, but also permits the user to specify his own thresholds of signal usability.

1.2 OBJECTIVES

The principal objective of this report is to illustrate the variety of information available from the use of PACE and how the information can be used to evaluate Omega system performance. Within this general framework, the work described in this report has three specific objectives:

(1) Relate PACE results for system availability (SPA II) to earlier system availability results (SPA I)

(2) Compare P_{SA} results for the globe and an oceanic region, and for various values of the thresholds specified by the signal coverage access criteria

(3) Evaluate/estimate the system availability index (P_{SA}) which would be experienced by a user equipped with a conventional aircraft Omega receiver.

The first objective seeks to provide a proper reference for interpreting the SPA II numerical results as well as to determine the effect of the new signal coverage database on P_{SA}. The second objective seeks to determine how global and regional P_{SA} values differ and the sensitivity of P_{SA} to the user-selectable thresholds of the signal access criteria in order to guide the recommendation of selecting thresholds. The "user-interpreted" P_{SA} indicated in the third objective is expected to differ from that computed by PACE simply because the signal usability/deselection algorithms found in typical Omega receiver/processors are much less sophisticated than those included in PACE. Thus, signals sometimes used by conventional aircraft receivers would not be considered usable based on signal access criteria recommended for use with PACE (see Section 4.2). For all three objectives, the analysis is limited to the primary Omega signal frequency of 10.2 kHz.

1.3 APPROACH

The kinds of available information and types of problems which may be addressed by the system availability model are best illustrated by selected applications. These applications may be described in terms of scenarios which postulate specific system conditions or configurations, e.g., reduced power levels or off-air conditions at one or more stations. System performance is then analyzed under each of these system configurations.

1.3.1 System Configurations

The system conditions/scenarios selected for analysis are defined in terms of the following configurations:

(1) All transmitting stations at full power (10 kW effective radiated power at 10.2 kHz)

(2) All transmitting stations at full power except for Station C (Hawaii) at 2.5 kW (6 dB power reduction)

(3) All transmitting stations at full power except for Station C (Hawaii) at 0 kW (Hawaii permanently off air).

These configurations were suggested by the results of detailed *in situ* Hawaii antenna cable/connector examination and repair/replacement cost estimates available at the time this effort was initiated. Configuration (3) specifies permanent station off-air, rather than temporary off-air, to enforce a zero probability of Hawaii station signal on air. This is necessary because the System Availability Model takes the month as the smallest time unit over which the probabilistic measure, P_{SA}, is projected*. PACE has additional features which permit calculation of P_{SA} under three different conditions during the month when a given station is scheduled for annual maintenance:

- The event that a station is in an off-air condition (unscheduled, scheduled, or annual maintenance) is treated probabilistically (nominal case)
- The station designated for annual maintenance during the given month is off-air (deterministic; worst case)
- The station scheduled for annual maintenance during the given month is on-air (deterministic; best case).

By specifying Hawaii permanently off air, the above three PACE options yield the same result.

To satisfy the objectives, comparison of P_{SA} must be made under a wide variety of conditions. For a very limited set of conditions, interpretation of the P_{SA} results can be conflicting and misleading, e.g., for a single hour/month within a small geographic region, changing Hawaii's status from on-air to off-air may show no change in P_{SA} — hardly a proper overall assessment. On the other hand, the large dimensionality of the problem makes an exhaustive comparison impractical (and probably incomprehensible). As a result, comparisons are made in terms of *diurnal* P_{SA} *behavior*,

---

*This does not conflict with the notion of computing P_{SA} at a given hour/month, since, in that case, the model interprets P_{SA} as the probability of successful Omega use for *any* day at that hour within the given month.

since P_{SA} (and virtually all other measures involving signal coverage) depend sensitively on the UT hour. Thus, in each of the approaches outlined below, P_{SA} diurnal behavior is studied/compared under particular conditions for each of the three configurations listed above.

1.3.2 Approach to Comparing SPA I and SPA II P_{SA} Results

If the input conditions are identical, SPA I and SPA II P_{SA} results differ only because of the corresponding differences in the signal coverage databases. Thus, to properly compare the P_{SA} results, the conditions governing the SPA I and SPA II calculations must match as closely as possible. The input conditions cannot be made identical since the SPA I and SPA II signal coverage data are based on two somewhat different propagation models/algorithms and the signal parameter computation results were prepared and stored differently.

The principal method of insuring that the input conditions for the SPA II P_{SA} results are as similar as possible to the SPA I P_{SA} results is to emulate the known SPA I procedures using the available SPA II database information. The emulation is done primarily by adjusting the signal coverage access criteria as explained in Section 2.1. The complete emulation involves additional information external to that in the signal coverage database, e.g., the station reliability database and geographic regional weights. Though not strictly part of the signal coverage database, a collective signal criterion known as GDOP (Geometric Dilution of Precision) is included in the PACE database to provide information on the relative accuracy achievable by different station/signal combinations. Because SPA I and SPA II definitions of GDOP are different (see Section 2.1.2), the SPA II threshold value for this criterion must also be estimated to emulate the same degree of signal/signal set exclusion.

1.3.3 Approach to Comparing P_{SA} Results for Different Regions and Various Signal Coverage Access Criteria Thresholds

To clearly indicate the effect of changing signal access criteria thresholds, the P_{SA} calculations are based solely on the SPA II database and default values for those signal access criteria remaining fixed. Specifically, P_{SA} diurnal behavior for several SNR thresholds is analyzed to determine the dependence of system availability on minimum receiver tracking levels or, equivalently, station power levels. Similarly, P_{SA} diurnal behavior for several phase deviation thresholds is examined for any threshold values which produce critical behavior of the system availability.

As an example of the effect of changing conditions on P_{SA}, a comparison is made between the P_{SA} diurnal behavior for the globe and for an oceanic region. Specifically, the global P_{SA} diurnal behavior is compared with that for the North Atlantic region for several months of the year. This analysis attempts to determine similarities/dissimilarities between global and North Atlantic regional P_{SA} diurnal behavior.

1.3.4 Approach to Comparing P_{SA} Results For Several Omega Receiver Signal Deselection Algorithms

P_{SA}, as computed by PACE, is based on the System Availability Model using the new signal coverage database containing the most recent and rigorously calculated signal parameter prediction data available. Also, in computing P_{SA}, PACE "normally" uses default signal coverage access criteria which are believed to best represent the capabilities of conventional Omega receivers on airborne platforms. The resulting P_{SA} value is then the most accurate representation of system availability, *assuming* that:

- Conventional Omega receiver/processor algorithms select/deselect signals based on the most recent (and presumed accurate) signal parameter data, i.e, that used in the PACE database
- The default signal access criteria used in PACE are consistent with the capabilities of conventional receivers.

Because of delays in signal coverage information dissemination coupled with receiver model update cycles, conventional Omega receiver/processor algorithms do not include the most recent signal prediction data contained in the PACE database. The signal selection/deselection algorithms (those requiring external information) commonly in use now are based on published signal coverage results from the early to mid 1980's (see Ref. 3). An exact calculation of P_{SA} using coverage information supplied by these algorithms is highly impractical since it would mean resurrecting the earlier coverage data and integrating it into the current System Availability Model/Algorithm. However, the earlier coverage information was also based on signal access criteria generally different from those of the PACE default signal access criteria. The difference in signal access criteria is partly due to perceived differences in Omega receiver capabilities (over the last 10 years) and different formats for the available data. With the 24-hour/4-month/2-frequency signal coverage database contained in PACE, it is possible to emulate many different kinds of signal access criteria.

The approach taken here is to emulate the signal access criteria used in the earlier signal coverage calculations/diagrams upon which the currently used signal selection/deselection algorithms are based. Although based on the same signal coverage data, signal selection/deselection algorithms in conventional Omega receivers differ in implementation. These differences arise primarily from the degree of reliability ascribed to "near-modal" signals. Signals with even a low probability of modal behavior are usually avoided; however, when usable signals are otherwise scarce, near-modal signals may be tracked to gain some navigation information. The uncertainty in modal assignment stems from the fact that earlier coverage information was available at only two global times. "Modal maps" were also provided which indicated expected regions of modal behavior for each station's 10.2 and 13.6 kHz signal at times when the signal path is entirely dark. However, since no information was available at arbitrary times when the signal path is not entirely dark, modal assignment rules were developed to determine the time intervals for paths during which the signal is modal.

In this approach, three generic modal assignment rules, which are believed to bracket those currently implemented in Omega receivers, are emulated by appropriately formulating signal coverage access criteria for PACE execution. The results, then, indicate the effective system availability experienced by a user applying one of the signal deselection algorithms. These values of P_{SA} are compared to those obtained with the PACE default signal access criteria. The comparison can show if there are wide differences in P_{SA} between the various modal assignment rules and whether improved receiver deselection algorithms will result in an increase or decrease in system availability.

1.4 REPORT OVERVIEW

The succeeding chapters are arranged to address the three objectives listed in Section 1.2. Thus, Chapter 2 focuses on comparison of P_{SA} results for SPA I and SPA II for various times and other conditions. The effects on P_{SA} of model inputs/conditions, such as geographic region (including the globe) and signal access criteria thresholds, are explored in Chapter 3. Chapter 4 addresses the comparison of P_{SA} results as would be experienced by users of conventional aircraft-based Omega receivers containing signal deselection algorithms derived from earlier signal parameter data. P_{SA} comparisons of three generic modal deselection algorithms are made, referenced to the "baseline" conditions of the PACE default signal access criteria. Finally, a summary of the results together with conclusions and recommendations are given in Chapter 5.

2. COMPARISONS OF THE OLD (SPA I) AND NEW (SPA II) P_{SA} RESULTS

The original Omega System Availability Model documentation (Ref. 1) includes sample calculations of global P_{SA} under various conditions based on 10.2 kHz signal coverage data generated about 1980 (Ref. 4). The coverage data are specially formatted as fractions of the globe covered by each combination of three or more station signals (global coverage elements) for P_{SA} calculation. As noted in Section 1.1, this data is specified for 0600 and 1800 UT for any day in the months of February, May, August, and November. The signal coverage access criteria are already "built in" to this data since a "covering signal" is one whose signal parameter data satisfy the signal access criteria. Results of P_{SA} calculations carried out using this methodology are known as SPA I P_{SA} results. Similarly, P_{SA} results from PACE calculations using the 24-hour/4-month/2-frequency signal coverage database with the appropriate 10.2 kHz signal coverage access criteria are known as SPA II P_{SA} results.

In this chapter, SPA I and SPA II P_{SA} results are compared by adjusting the signal access criteria used in PACE to emulate the conditions under which the SPA I calculations were performed. The resulting differences between the SPA I and SPA II P_{SA} values should only arise from the improvements in the VLF propagation models from which the signal coverage data are obtained.

The signal coverage data/access-criteria directly affect only the signal coverage component of the System Availability Model*. In the original form of the model, the signal coverage component is entirely deterministic and randomness is introduced through the station reliability component. SPA I P_{SA} results are based on station reliability figures derived from historical reports of monthly/quarterly/annual station reliability statistics covering a three-year period. No variation in the other two components (receiver reliability/availability and user geographic regional priority) is included in the SPA I P_{SA} results. Thus, when comparing SPA I and SPA II results, the same reliability database, as well as the same effective signal coverage access criteria, must be employed.

* The signal access criteria have an indirect effect on the receiver reliability component through the assumed class of receiver.

2.1 SIGNAL COVERAGE ACCESS CRITERIA/STATION RELIABILITY DATABASE

2.1.1 SPA I Coverage Access Criteria/Reliability Database

The signal coverage access criteria used to produce the signal coverage data from which the SPA I P_{SA} results are computed are as follows:

- Signal-to-noise ratio (SNR) > -20 dB (100 Hz bandwidth (BW))
- Phase deviation < 20 centicycles (cec).

The "signal" used in the SNR criterion refers to the amplitude of the total (mode-sum) 10.2 kHz signal computed for a given station-receiver path over the surface of the earth for a given time. The "noise" in SNR refers to the noise envelope amplitude obtained from the CCIR noise prediction model (Ref. 5) in the 100 Hz BW at a center frequency of 10.2 kHz for the given time and receiver location. The phase deviation is obtained from the difference, D, between the phase of the mode-sum signal and the Mode 1 signal. Since D may be expressed in terms of whole cycles and fractions of a cycle, the actual phase deviation is computed as the magnitude of the difference between D and the nearest whole-cycle value (e.g., if D=1.83 cycles, the phase deviation is 0.17 cycle). Both of these quantities refer to the signal's "short path", i.e., the shorter of the two great-circle arcs between a transmitting station and a receiver over the (assumed spherical) earth.

In addition to the above criteria, the Geometric Dilution of Precision (GDOP) is included in the SPA I P_{SA} calculations as a collective signal access criterion, i.e., all signals determined to be usable on an individual basis were evaluated geometrically to determine their collective use for accurate position fixing. Signal coverage data used for the SPA I P_{SA} results are available for the two cases in which this criterion was applied and not applied. The particular GDOP criterion used in the signal coverage data supporting the SPA I P_{SA} calculations is applied to those regions/times in which only 3 or 4 10.2 kHz signals are accessible. For these two situations, the GDOP criterion is given as:

- If 3 signals are accessible, the GDOP must be less than 1 kilometer/centicycle of phase-difference error
- If 4 signals are accessible, the lowest GDOP of all 3-station subsets must be less than 1 kilometer/centicycle of phase-difference error

The signal parameter calculations upon which the SPA I P_{SA} results are based include a test to insure that any signal defined as "accessible" or "covered" has a Mode 1 component amplitude that is at least as large as the magnitude of the phasor sum of all other component modes. This test is applied independently of the value computed for the phase deviation to insure that a covered signal's Mode 1 component is not dominated by higher-order modes.

The SPA I P_{SA} results are based on station off-air statistics from 1985, 1986, and 1987 (Ref. 1, Table 3.4-1). Since there is little year-to-year change in P_{SA} for the SPA I results (Ref. 1, Chapter 3), only the 1985 station reliability database is used to obtain the SPA II P_{SA} results presented here for comparison.

2.1.2 SPA II Signal Coverage Access Criteria which Emulate SPA I Conditions

The signal coverage access criteria specify conditions on signal coverage parameters to determine signal usability. Most of the SPA II/PACE signal access criteria contain threshold values as input to the computation, although a set of threshold values (which make up the PACE default signal access criteria) are generally recommended. Each set of calculated signal parameters corresponds to a path (Omega transmitting station and receiver location), time (hour/month), and frequency (10.2 or 13.6 kHz).*

Spatially, each set of signal parameter data is associated with a path from each of the eight transmitting stations to each of the 444 receive points distributed uniformly throughout the globe. Located at the center of "cells" (the unit of spatial resolution of the database), the receive points are assumed to represent signal reception from a given station throughout the cell. The cells are 10° (latitude) by 10° (longitude) near the equator but are redefined in the higher latitudes to maintain an approximately constant area of one square megameter (10^6 km^2). Table 2.1-1 defines the cell latitude and longitude dimensions as a function of latitude.

Temporally, the data is referenced to signal paths (defined by transmitting station/cell pairs) at fixed global times. The signal path calculations are made on the hour for each of the 24 UT hours. Since, for a given hour, the signal propagation parameters show definite change from month-to-month but little change day-to-day within a month, the signal calculations are made for the 15th day in each of four months: February, May, August, and November. Moreover, since the month-to-month change in the hourly signal propagation parameters is not too large, the signal data may be reliably interpolated over the two months separating "neighboring" coverage months. Thus, the information in the database is referenced to 24 hours and 12 months.

*Only 10.2 kHz signals are considered in this report (in consonance with SPA I P_{SA} results)

Table 2.1-1 Latitude/Longitude Dimensions of Cells in Grid Structure for Signal Coverage Database (Matrix Format)

LATITUDE RANGE*	LATITUDE DIMENSION OF CELL	LONGITUDE DIMENSION OF CELL	NUMBER OF CELLS IN BOTH HEMISPHERES
0° to 40°	10°	10°	288
40° to 60°	10°	15°	96
60° to 75°	15°	15°	48
75° to 90°	15°	60°	12
TOTAL NUMBER OF CELLS = 444			

*Same for northern and southern hemisphere

Specifically, the parameters of the propagated Omega signal stored in the PACE database are, for a given path, time, and frequency:

- Short-path signal-to-noise ratio (100 Hz BW) [SPSNR]
- Ratio of SPSNR to long-path SNR (100 Hz BW) [SP/LP]
- Short-path phase deviation (absolute value of difference between Mode 1 and Mode-sum phase modulo 1 cycle) [SPPD]
- Mode 1 dominance margin [M1DM]
- Path-terminator crossing angle (pertinent only if terminator crosses short path) [PTCA]
- Geometric Dilution of Precision [GDOP].

In the above, SP and LP refer to the shorter and longer arcs, respectively, of the great-circle path connecting transmitting station and receiver locations over the (assumed spherical) earth. In most cases, Mode 1 is the Omega signal's transverse magnetic (TM) modal component with the lowest phase velocity and attenuation rate; mode-sum refers to the sum of all modal components, i.e., the total signal. The Mode 1 dominance margin is the ratio of the amplitude of the Mode 1 amplitude to the interfering mode (IM) amplitude. The IM is the phasor sum of all modal components excluding Mode 1. The terminator is the great-circle boundary between day and night on the surface of the earth. The analytical form of the GDOP is derived from a navigation data processor model applicable to an airborne Omega receiver (Ref. 6).

To emulate the conditions under which SPA I P_{SA} results were obtained, the following coverage access criteria (SPA I-emulated criteria) are used in generating the SPA II P_{SA} results (using PACE) unless otherwise specified:

(1) SPSNR ≥ -20 dB

(2) SPPD ≤ 20 cec

(3) M1DM ≥ 0 dB (Dominant Mode selector ON; not invoked if Dominant Mode Selector OFF)

(4) SP/LP ≥ -99 dB (effectively disabled)

(5) PTCA ≥ 0 degrees (effectively disabled)

(6) GDOP ≤ 6.

These criteria are chosen primarily to emulate (as closely as possible) the conditions under which the SPA I P_{SA} values were derived. Since these criteria are used in executing PACE, they are defined so as to be consistent with the databases/algorithms embodied in PACE.

The first signal access criterion (involving SPSNR) is the same as the SPA I criterion given in Section 2.1.1 since the definitions of the quantities involved (mode-sum amplitude and noise) have not changed. The same is true of the second criterion (involving SPPD) although the allowable values of SPPD are limited by Criterion (3) through M1DM. In PACE, Criterion (3) can be invoked by setting the Dominant Mode selector ON or ignored by setting the Dominant Mode Selector OFF. M1DM normally has a fixed threshold value of 6 dB in PACE; a threshold value of 0 dB was obtained using a modified version of PACE. This threshold was selected to emulate the Mode 1 dominance condition for the SPA I calculations described above. Criteria (4) and (5) were selected so as to disable SP/LP and PTCA conditions which were not addressed in the coverage data used for the SPA I P_{SA} calculations. Criterion (6) involves GDOP, a collective signal criterion which is applied after individual signal access criteria have been applied. GDOP is generally defined as the dimensionless ratio of position error to appropriately scaled "measurement" error. The GDOP used in PACE is defined according to a particular model (Ref. 6) and differs from the GDOP specified in connection with SPA I results.

GDOP, as used in the coverage data underlying the SPA I P_{SA} results, is the ratio of the radial position-error standard deviation (km) to the standard deviation of phase-difference (LOP) error (cec) assuming a hyperbolic utilization mode with an LOP correlation coefficient magnitude of 0.5. As explained above, this GDOP is computed only for 3- and 4-station/signal sets and has an assumed upper limit threshold (when invoked) of 1 km/cec (LOP phase error). Using standard assumptions*, this threshold is equivalent to about 141.4 km/cycle (single-station phase error).

GDOP, as used in SPA II/PACE, is an analytic form derived from a model described in Ref. 6 and is computed for all station/signal sets in each cell. For *three* stations, the SPA I and SPA II GDOP values are proportional for any station geometry. In the case of *four* stations, the SPA I GDOP algorithm specifies the lowest GDOP of the four possible three-station combinations, while the SPA II GDOP is entirely different. For more than four stations, only SPA II GDOP values are available. The SPA I GDOP threshold can be transformed (through dimensional analysis) to an equivalent SPA II GDOP threshold. Thus, the SPA I threshold of 141.4 km/cycle given above is equivalent to a dimensionless SPA II GDOP threshold of 141.4/29.39118 = 4.8 for 10.2 kHz†. This dimensionless threshold must be further modified to account for the fact that only those locations/times covered by 3 and 4 station combinations are addressed by the SPA I GDOP criterion. The net effect is that SPA I results are less restrictive than those SPA II results using a GDOP threshold of 4.8 (or 5, since GDOP thresholds are specified only in whole number units in PACE) would imply. For this reason, a GLOP threshold of 6 (less restrictive) is selected as the SPA I "equivalent" GDOP threshold used in PACE.

2.2 P_{SA} COMPARISONS FOR VARIOUS HOUR/MONTH CONDITIONS

With the signal coverage access criteria now established that best represent the conditions under which the SPA I P_{SA} results were obtained, the comparisons with SPA II results can now be made. As mentioned above, since all conditions on the signal coverage and reliability data are the same, the P_{SA} results should reflect only the differences in the signal coverage parameters used by the SPA I and SPA II P_{SA} calculations.

Since the SPA I P_{SA} results are based on signal coverage data on specified only for the hours of 0600 and 1800 UT in the months of February, May, August, and November, P_{SA} results from SPA I are compared with those from SPA II (PACE) at the SPA I hours and months. However, as explained in Section 1.3.2, SPA II P_{SA} results are to be presented in the form of diurnal plots which indicate the hour-to-hour variation in system availability. In the plots, the hourly P_{SA} values (points) are connected with a spline curve to help distinguish overlaid curves and because it is thought to be

* Phase error standard deviations are equal for all signals; phase errors on different signal paths are uncorrelated.

† The GDOP threshold is made dimensionless by dividing by the wavelength (in kilometers) at 10.2 kHz.

a good approximation to inter-hour behavior. For comparison, the SPA I P_{SA} results for one or two UT hours are shown as isolated points relative to the continuous SPA II P_{SA} curve.

The plots illustrate, for a given coverage month, P_{SA} diurnal behavior for each of the three configurations listed in Section 1.3.1, i.e.,

(1) All transmitting stations at full power (10 kW effective radiated power at 10.2 kHz)

(2) All transmitting stations at full power except for Station C (Hawaii) at 2.5 kW (6 dB power reduction)

(3) All transmitting stations at full power except for Station C (Hawaii) at 0 kW (Hawaii permanently off-air).

Thus, the SPA II P_{SA} results are portrayed as three curves (each curve corresponding to one of the above configurations) overlaid on each figure. The comparable SPA I P_{SA} results are shown for Hawaii at 10 kW and Hawaii off-air for the following UT times:

- Hour 06 only in February, May, and August
- Hours 06 and 18 in November.

With this format, Figs. 2.2-1 to 2.2-4 show plots for the coverage months of February, May, August, and November.

For 0600 UT with Hawaii at 10 kW, Fig. 2.2-1 indicates that the SPA I P_{SA} result is lower by about 1-2% than the SPA II result for Hawaii at 10 kW *or* 2.5 kW in February. Figures 2.2-2 and 2.2-3 show that the SPA I P_{SA} result is about 1% *higher* than the corresponding SPA II result in May and August. Figure 2.2-4 indicates close agreement of SPA I and SPA II results in November at 0600 UT.

With Hawaii off-air, however, the SPA I and II P_{SA} results at 0600 UT exhibit a distinctly greater difference. Figures 2.2-1 to 2.2-4 show SPA I P_{SA} results 2-5% higher than the corresponding SPA II results for all coverage months at 0600 UT.

At 1800 UT, Fig. 2.2-4 shows close agreement between SPA I and II results in November, both with Hawaii at 10 kW and at 0 kW. Unfortunately, SPA I results are not available for other months, so that comparisons for February, May, and August cannot be made.

It is also interesting to note that, at 0600 UT, the SPA II month-to-month changes in P_{SA} are about the same (in magnitude) as those for SPA I when all stations are at full power; however, with Hawaii off-air, the SPA II month-to-month changes in P_{SA} are greater than those for SPA I.

Beyond the SPA I/SPA II comparisons, Figs. 2.2-1 to 2.2-4 reveal some noteworthy diurnal characteristics of system availability emerging from the SPA II results. The plots indicate that, except for UT hours 1900-2400, the effect on P_{SA} of reducing the Hawaii station transmitting power by 6 dB is small. This is explained by noting that the period 1900-2400 UT, during which the larger P_{SA} effect occurs, is coincident with local daytime at the Hawaii station in which coverage is least affected by modal interference. Since modal interference is insensitive to power level changes (strengths of all modes changed equally), it follows that coverage (and therefore also P_{SA}) is most affected when the station with the changing power level is in local daytime. Another interesting feature is that the month-to-month P_{SA} variation is approximately minimum at 0600 and 1800 UT. This feature is consistent with the rationale for the selection of 0600 and 1800 UT as the two hours for which the earlier coverage diagrams were developed, i.e., the two UT hours (separated by 12 hours) for which the terminator is at a maximum distance from any transmitting station. Thus, at each of these hours, the terminator position (with respect to any given transmitting station) is least likely to "cross over" a station as the months change.

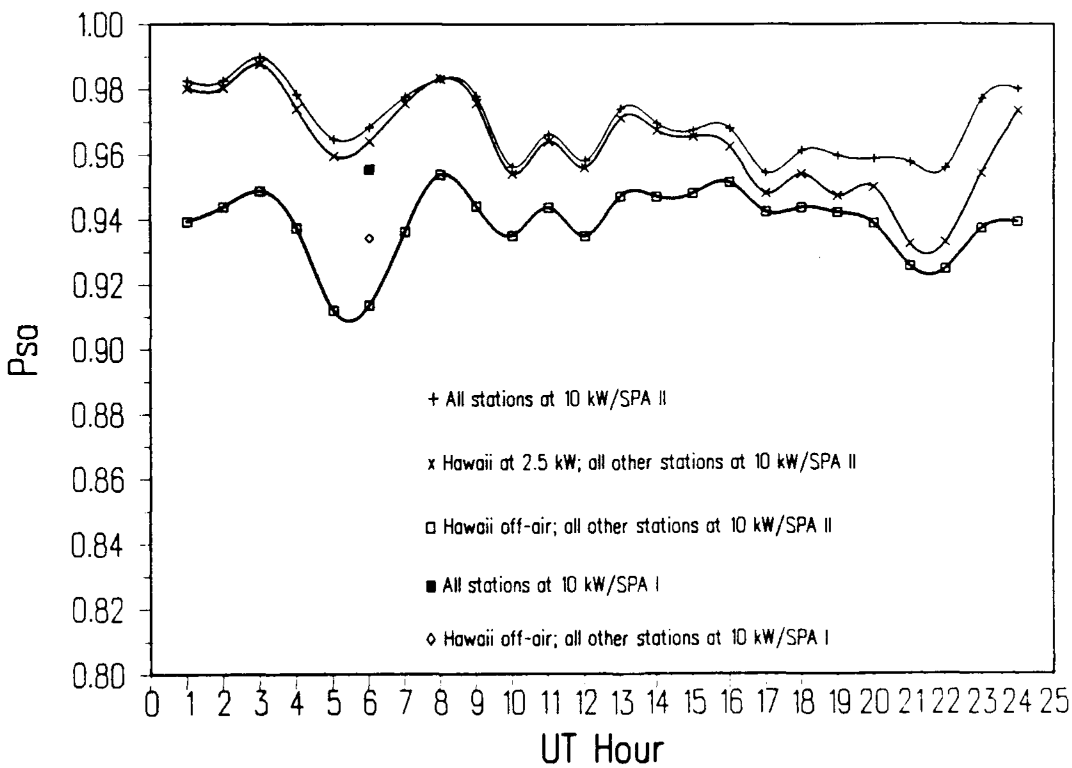

Figure 2.2-1 Effect of Hawaii Power Reduction on P_{SA} in February; SPA II Results Based on SPA I-emulated Signal Coverage Access Criteria

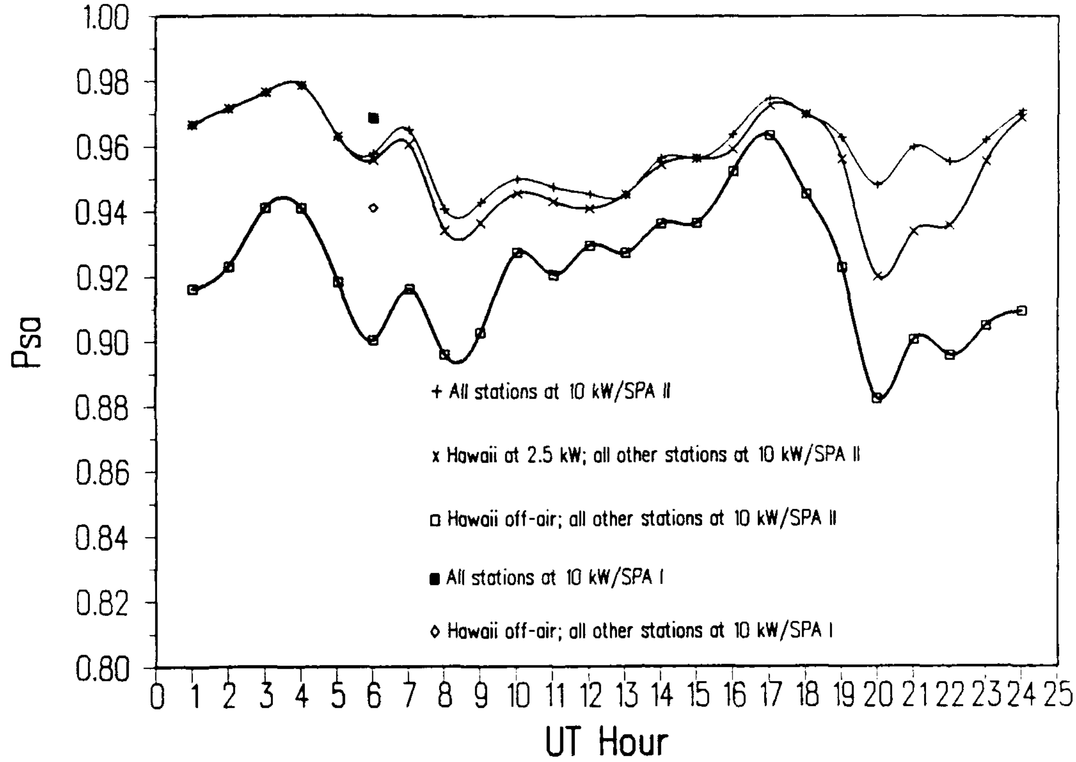

Figure 2.2-2 Effect of Hawaii Power Reduction on P_{SA} in May; SPA II Results Based on SPA I-Emulated Signal Coverage Access Criteria

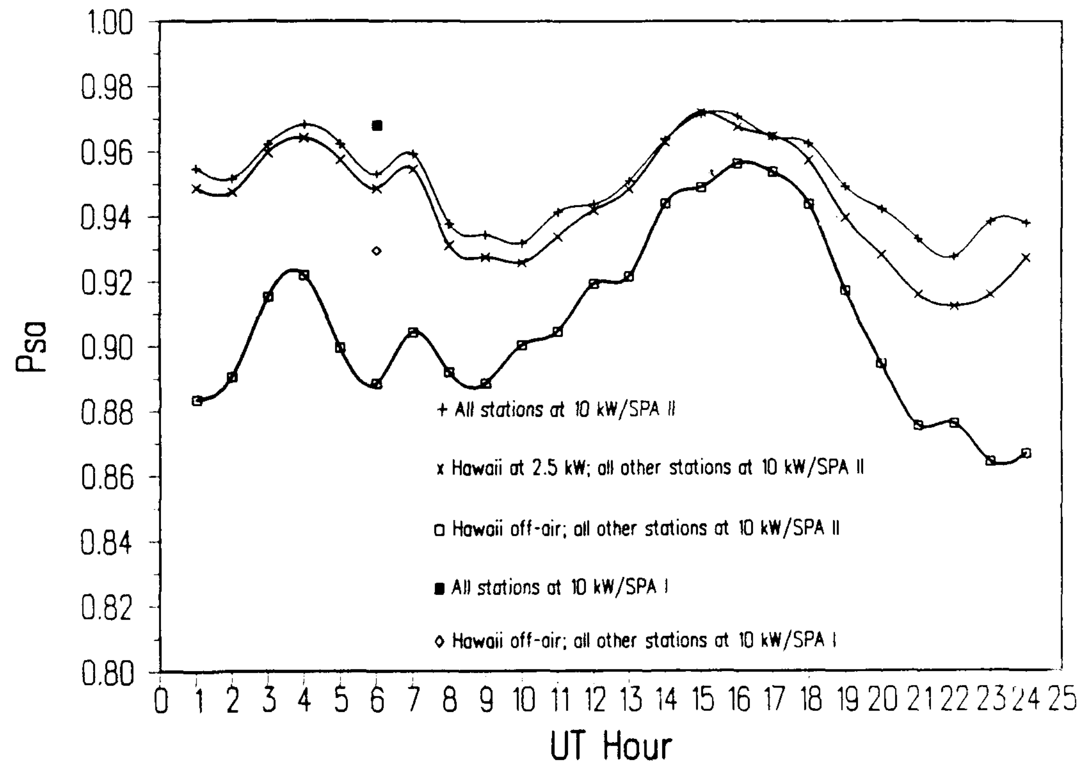

Figure 2.2-3 Effect of Hawaii Power Reduction on P_{SA} in August; SPA II Results Based on SPA I-Emulated Signal Coverage Access Criteria

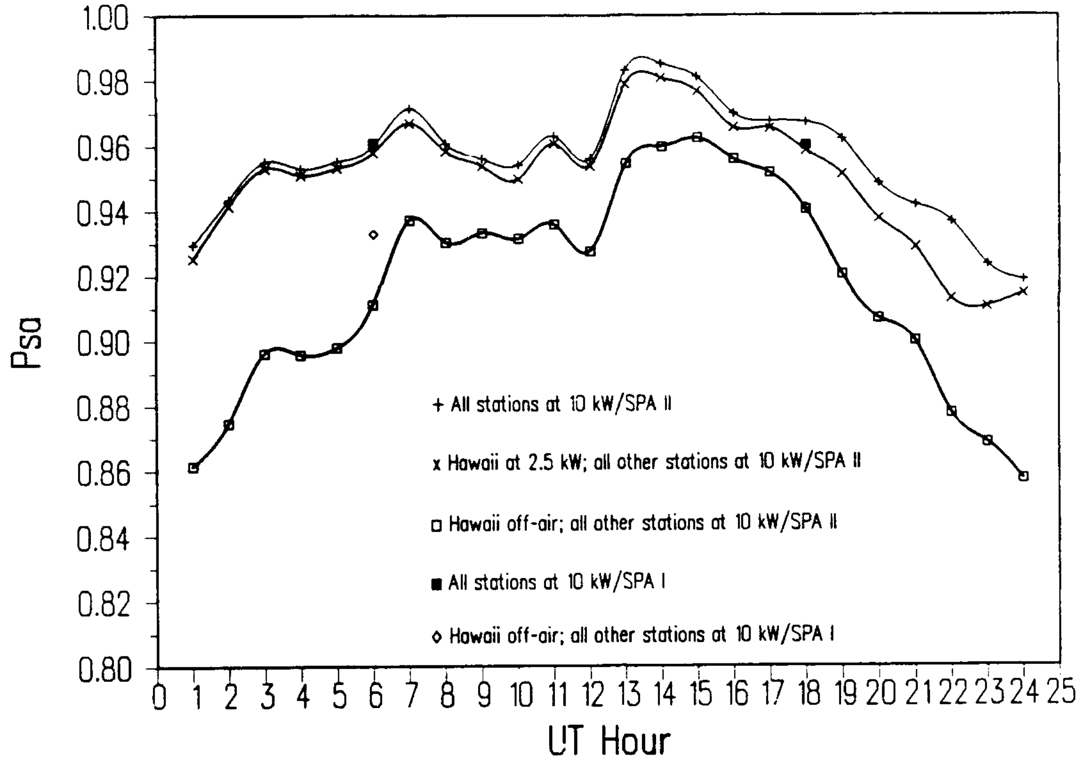

Figure 2.2-4 Effect of Hawaii Power Reduction on P_{SA} in November; SPA II Results Based on SPA I-Emulated Signal Coverage Access Criteria

2.3 P_{SA} COMPARISONS FOR VARIOUS GDOP THRESHOLDS

In this section, SPA I/SPA II P_{SA} comparisons are made with a GDOP criterion applied/not applied for November/1800 UT (the only hour/month for which SPA I P_{SA} results with/without GDOP restrictions are reported). As before, the SPA I-emulated signal coverage access criteria are used, except for the GDOP criterion threshold which is varied accordingly.

As explained in Section 2.1.2, the SPA I GDOP threshold of 1 kilometer per centicycle of phase difference error for three and four station coverage is "equivalent" to a threshold of 6 in terms of the SPA II GDOP. This equivalence is inferred from a dimensional analysis argument in Section 2.1.2. From another viewpoint, the two equivalent thresholds should correspond to the same "percentile" in a GDOP distribution over all possible station combinations and receiver locations. Knowledge of this GDOP distribution is also useful for determining an appropriate range of GDOP thresholds for examining the sensitivity of P_{SA} to GDOP criteria.

A SPA II GDOP distribution is obtained by computing GDOP (using the analytic form given in Ref. 6) for all possible combinations (219) of three or more stations at the centers of each of the

444 PACE-defined cells (see Table 2.1-1). The GDOP values are sorted into bins of unit GDOP from 1 to 255. Figure 2.3-1, which shows a plot of the resulting histogram (or discrete probability density function), is given in log-log form because of the extreme sharpness of the density function near a GDOP of 2. The quasi-linear shape of the density function for GDOP > 4 suggests a negative powe. law form with ar. exponent of –2.2. The scatter which appears in the lower right-hand portion of the figure is an artifact of the log-log plot, i.e., the departure of the histogram from monotone behavior is magnified when the curve "flattens out" (as it would on a linear plot) and the apparent bin density increases. From this density function, the following GDOP statistics are computed:

Average = 2.87 90th Percentile = 3
Standard Deviation = 8.18 95th Percentile = 6
Median (50th percentile) = 2 99th Percentile = 23.

The extreme peakedness of the distribution is evident from these statistics, e.g., one standard deviation from the average corresponds to a GDOP well above the 95th percentile.

Figure 2.3-2 shows a scatter plot comparing the "old" (SPA I) GDOP and the "new" (SPA II) GDOP. The plot includes approximately 10% of the total three and four station combinations in the

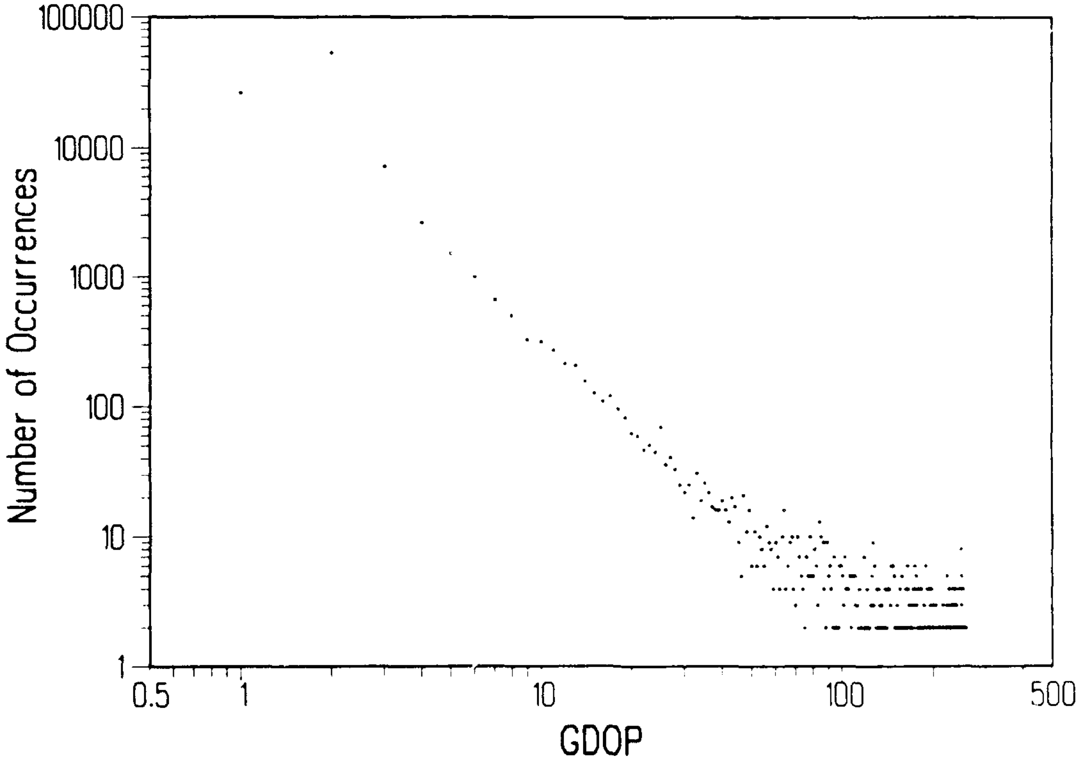

Figure 2.3-1 Histogram of Global SPA II GDOP Values

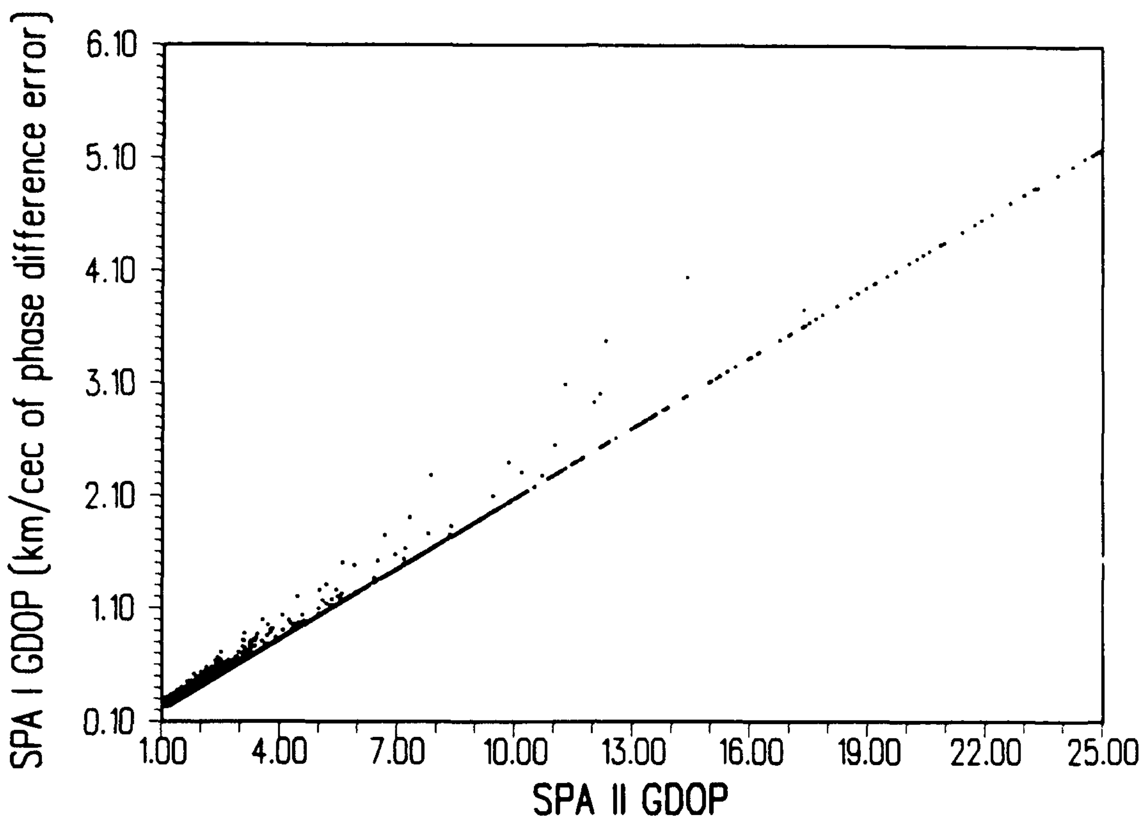

Figure 2.3-2 Scatter Plot of SPA I GDOP vs SPA II GDOP for Three and Four Station Combinations

distribution described above. These are further restricted to include those combinations with SPA II GDOPs less than 25. The plot indicates a large concentration of points with (SPA II) GDOP less than about four and a significant correlation between the two GDOP definitions. The collection of points which form a diagonal (from lower left to upper right) correspond to a line of slope 1/4.8, i.e., the reciprocal of the ratio between the SPA II GDOP and SPA I GDOP thresholds obtained in Section 2.1.2. The points on this diagonal line correspond to 3-station combinations and points off the diagonal correspond to the lowest of the four 3-station GDOPs obtained from each 4-station combination. The plot shows that all of the points lie to the left of this line, i.e., in the region where the old GDOP exceeds the equivalent new GDOP. This confirms the fact that adding a fourth station never increases (and, in fact, almost always reduces) the GDOP established by the best triad.

Figures 2.3-3 and 2.3-4 show diurnal P_{SA} behavior during the months of May and November (other months have intermediate behavior) for SPA II GDOP thresholds of 2, 3, 6, and 23. From the GDOP distribution given above, this corresponds to exclusions of station combinations varying from 50% of the total combinations to 1%. The higher GDOP thresholds permit a greater number of usable station/signal sets which, in turn, exhibit upward-shifted diurnal P_{SA} curves. No comparable

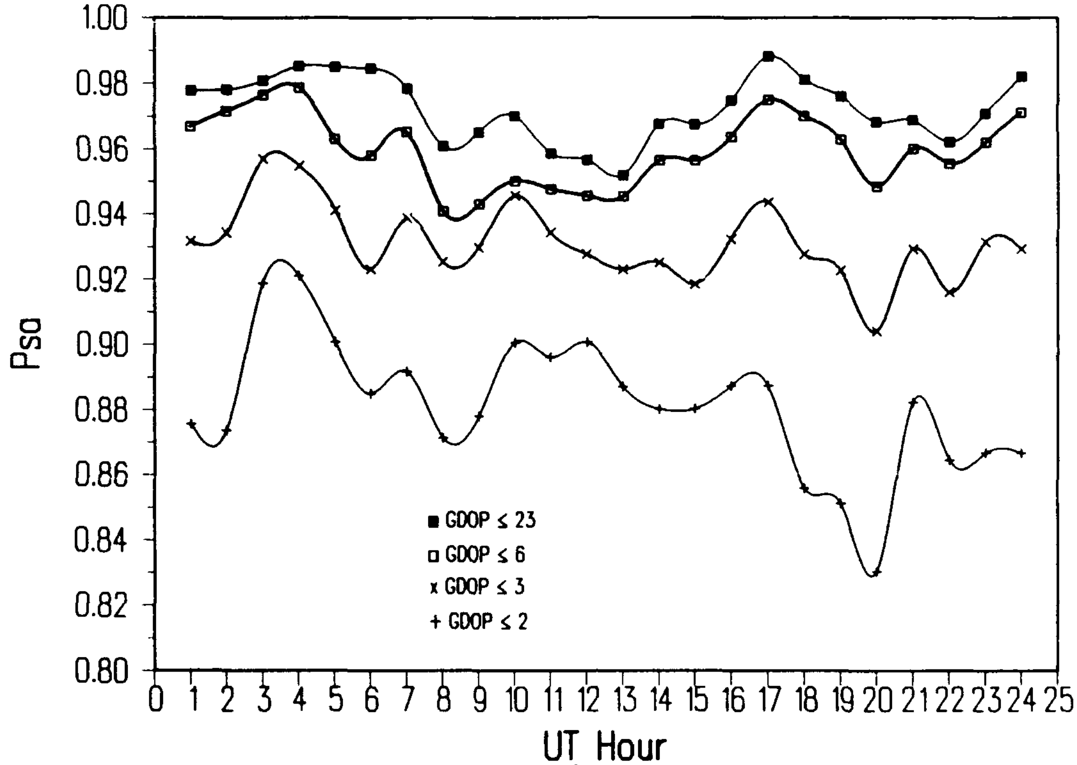

Figure 2.3-3 P_{SA} Diurnal Behavior in May for several GDOP Thresholds; Results based on SPA I-emulated Signal Coverage Access Criteria

SPA I results were obtained for May (Fig. 2.3-3), but it is interesting to note that, for this month, as well as November, GDOP thresholds of 2 and 3 significantly reduce system availability. This is consistent with the GDOP distribution described above indicating that about 50% of the possible station combinations have GDOPs less than 2. Figure 2.3-4 shows SPA I results at 1800 UT for two cases:

- A GDOP threshold of 1 km/cec (of phase-difference error)
- No GDOP restriction.

These correspond to SPA II GDOP criteria of 6 (for the reasons given in Section 2.1.2) and 23 (1% of all GDOPs excluded), respectively. The figure shows that the SPA I P_{SA} results lie about 1% below the corresponding SPA II results. The P_{SA} diurnal behavior associated with successive GDOP thresholds changes less as the corresponding GDOP distribution percentiles become higher and closer. Thus, GDOPs of 6 and 23 correspond to GDOP distribution percentiles of 95% and 99%, respectively (difference of 4%) and the P_{SA} curves associated with these two GDOP thresholds are noticeably closer than other pairs although the distribution percentiles corresponding to 6 and 3

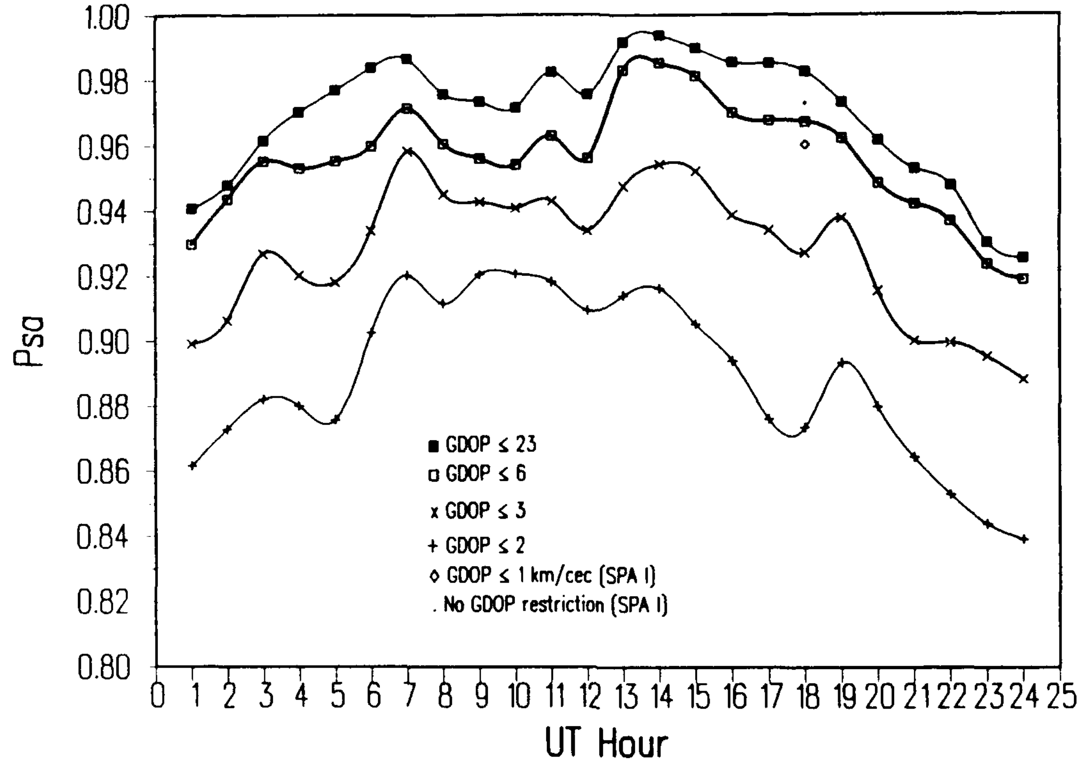

Figure 2.3-4 P_{SA} Results in November for Several GDOP Thresholds; SPA II Results based on SPA I-emulated Signal Coverage Access Criteria

differ by only 5%. This property holds for both months shown although the diurnal curves (for the corresponding thresholds) differ substantially in shape.

In summary, the information presented in this chapter includes comparison of the system availability index (P_{SA}) computed by PACE (SPA II results) with P_{SA} computed using earlier coverage information (SPA I results). The conditions for the PACE calculations are carefully prepared to match the earlier coverage conditions so that the comparison reflects only the differences due to improved signal coverage parameter calculations. The differences are generally found to be small ($\leq$2%) over the rather limited set of hour/month conditions for which SPA I P_{SA} calculations were made. The largest differences (~2-5%) are found at 0600UT when the Hawaii station is off-air. A SPA I/SPA II P_{SA} comparison is also made for a situation in which GDOP is applied/not applied as a collective signal criterion. In this situation, the SPA I and SPA II results differ by about 1%. Thus, over the very limited conditions for which comparison can be made, the more accurate signal coverage database yields P_{SA} values which are about 1-5% lower than those computed using the earlier signal coverage information. To generalize further on such limited comparisons is not warranted; however, a 1-5% P_{SA} difference is consistent with the fact that the signal propagation model from which the SPA II coverage database was generated is an *improvement* upon (as opposed to a completely new model) the model from which the SPA I coverage information was generated.

3. EFFECT OF GEOGRAPHIC REGION AND SIGNAL COVERAGE ACCESS CRITERIA ON P_{SA}

In this chapter, the analysis focuses on SPA II P_{SA} results only. As noted in Chapter 1, P_{SA} depends on a number of conditions associated with the four system components of the System Availability Model. To provide a better understanding of system availability, the dependence of P_{SA} on some of these conditions is explored in this chapter.

First, alternative conditions associated with the user geographic regional priority component are considered in terms of their effect on P_{SA}. In Chapter 2, P_{SA} is computed over the entire globe, although SPA I and SPA II approaches to global computation are different. Here, global results are compared with P_{SA} computed only over the North Atlantic region. This is accomplished by employing the model's user geographic regional priority component to weight the cells that cover the North Atlantic by a fixed number (e.g., 1) and all other cells zero. This weighting provides uniform user geographic priority (for Omega use) over the North Atlantic.

The conditions imposed on the signal coverage component of the System Availability Model are also varied in this Chapter to determine their effect on P_{SA}. In particular, the sensitivity of P_{SA} to certain signal coverage access criteria thresholds (excluding changing GDOP thresholds analyzed in Chapter 2) is examined. A sensitivity analysis of this kind is useful in establishing alternative signal access criteria thresholds for different classes of users or for investigating system options.

3.1 BASELINE CONDITIONS/SIGNAL COVERAGE ACCESS CRITERIA

When comparing SPA II P_{SA} results for different conditions involving the System Availability Model components, it is convenient to establish a set of baseline, or default conditions as a reference. Thus, when varying a specific condition, the other conditions are fixed at the default values.

The baseline conditions are given as follows:

a) PACE default reliability statistics
b) Uniform weighting of entire globe
c) PACE default signal coverage access criteria:
   (1) SNR $\geq$ −20 dB (100 Hz BW)
   (2) SPPD $\leq$ 20 cec

(3) M1DM $\geq$ 6 dB (Dominant Mode selector ON)
(4) SP/LP $\geq$ 6 dB
(5) PTCA $\geq$ 5°
(6) GDOP $\leq$ 6.

The PACE default reliability statistics, comprising a station on-air/off-air probability database incorporating both historical data and projected average values, are given in Reference 7. The abbreviations used above for the PACE default signal coverage access criteria are defined in Section 2.1.2. These criteria prescribe what are believed to be the most reliable thresholds of the signal parameters based on known capabilities of conventional Omega receivers on airborne platforms. Comparison of these criteria with those used in the SPA I/ SPA II analysis of Chapter 2 shows that the M1DM threshold is increased from 0 to 6 dB and the short-path/long-path and path-terminator crossing angle criteria are no longer disabled. The M1DM margin of 6 dB is needed to account for uncertainties in the ionosphere/signal propagation model. A simple phasor model of Mode 1 and IM ("interfering mode", i.e., the non-Mode 1 part of the total signal) can be used to show that M1DM and SPPD are coupled such that M1DM $\geq$ 6 dB implies that SPPD cannot exceed about 8 cec. The SP/LP criterion also provides a margin of safety against long-path signal reception. The PTCA criterion is imposed to prevent lane slip due to a fast transition or possible lateral reflections/refractions from the terminator (Ref. 8).

3.2 COMPARISON OF GLOBAL AND NORTH ATLANTIC P_{SA} RESULTS

In this section, P_{SA} results for the globe and the North Atlantic region are compared for several months and for the three configurations specified in Section 1.3.1. The baseline conditions for the PACE calculations are specified in Section 3.1. The condition to be adjusted for analysis is the specification of the geographic region for P_{SA} calculation which is alternately given by the globe (baseline) and the North Atlantic region.

Figure 3.2-1 shows a PACE weights display in which the weights for both the globe (all cells weighted 1) and the North Atlantic region (all constituent cells weighted 1) are overlaid. The cells comprising the North Atlantic region were chosen to be north of latitude 10° North (to exclude characterizing the equatorial central Atlantic). Cells bordering neighboring land masses, e.g., North America, were selected if they included mostly ocean areas to ensure appropriate characterization of the North Atlantic Ocean by cell center signal parameters. The 27 cells representing the North Atlantic region are outlined with thicker borders in the figure.

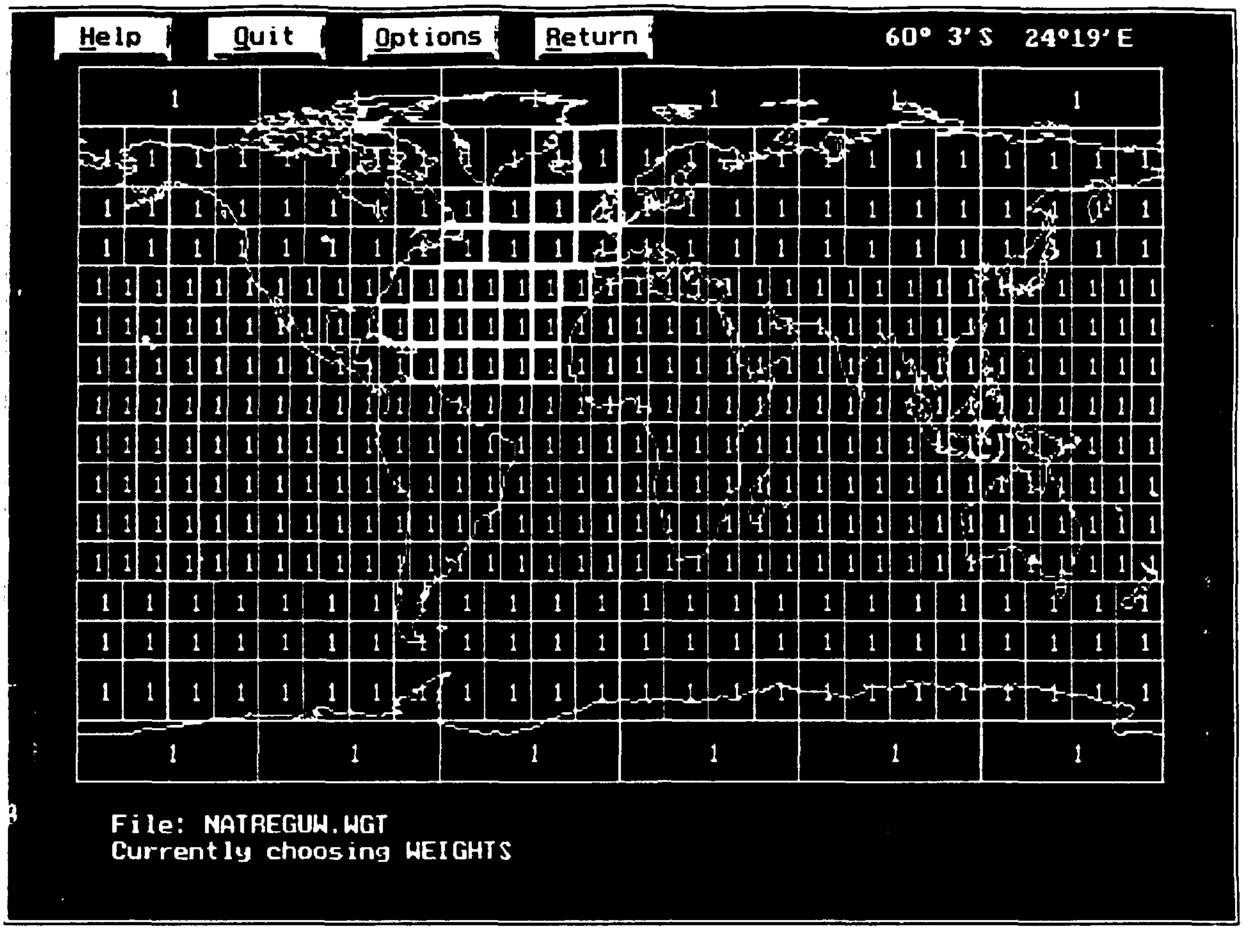

Figure 3.2-1 PACE Weights Display showing Uniformly Weighted Cells of Entire World and North Atlantic Region (cells with thicker border lines)

Figures 3.2-2 and 3.2-3 compare global and North Atlantic P_{SA} diurnal behavior for the months of May and November, respectively (February and August are not shown since they exhibit intermediate behavior). The plots show that P_{SA} for the North Atlantic is higher than that for the globe at all hours in May, but only during the hours 0200-1900 UT (excluding 1500 UT) in November. The lower P_{SA} values during the hours 2000-0100 UT are primarily due to the deselection of the Liberia signal which becomes highly modal as paths to the northwest and west from the Liberia station across the North Atlantic become mostly dark. P_{SA} improves significantly at 0200 UT as signals on paths to the North Atlantic from westerly stations (e.g., Hawaii) become dominated by the lower nighttime attenuation and extend their range into the North Atlantic. This effect is more pronounced in November than May because of the smaller fraction of daylight over the northern hemisphere. The P_{SA} reduction during these hours is further enhanced by the Australia station's larger off-air probability during November (Australia's maintenance month). During the hours 2000 UT to about 0600 UT, Australia supplies an important daytime signal throughout the Pacific when some other signals are range-limited due to the daytime path attenuation. Thus, P_{SA} is more sensitive to Australia's higher off-air probability during these hours.

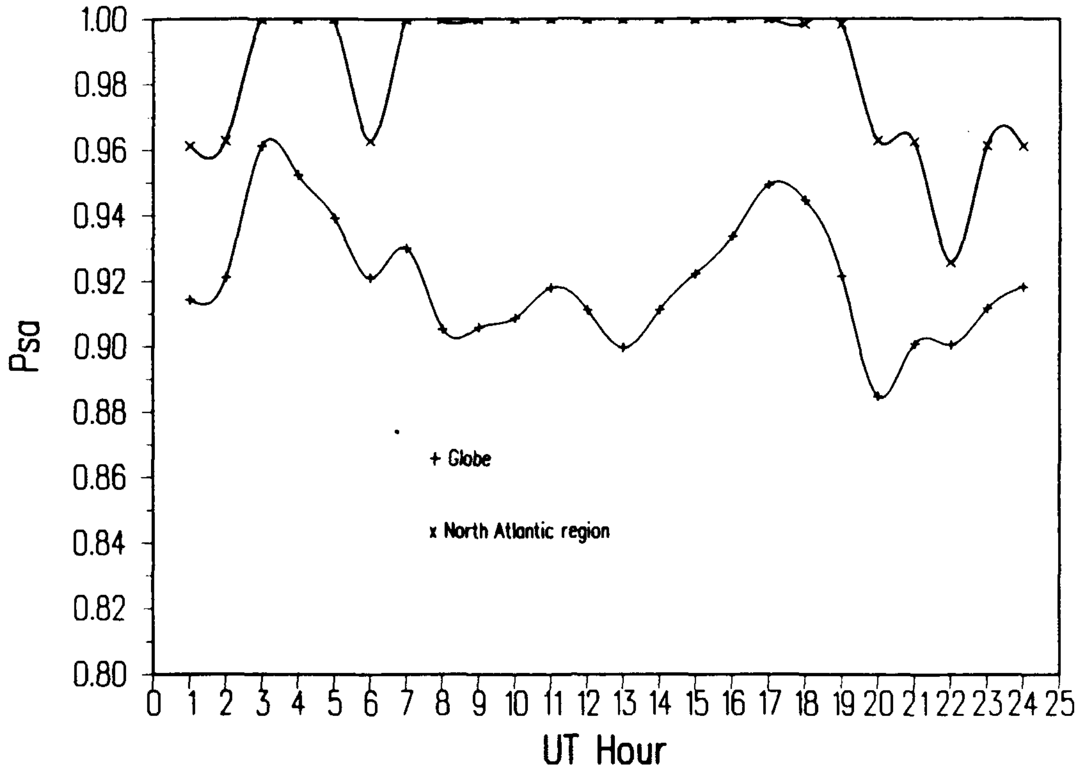

Figure 3.2-2 Comparison of Global and North Atlantic P_{SA} Diurnal Behavior for May using Default PACE Signal Coverage Access Criteria

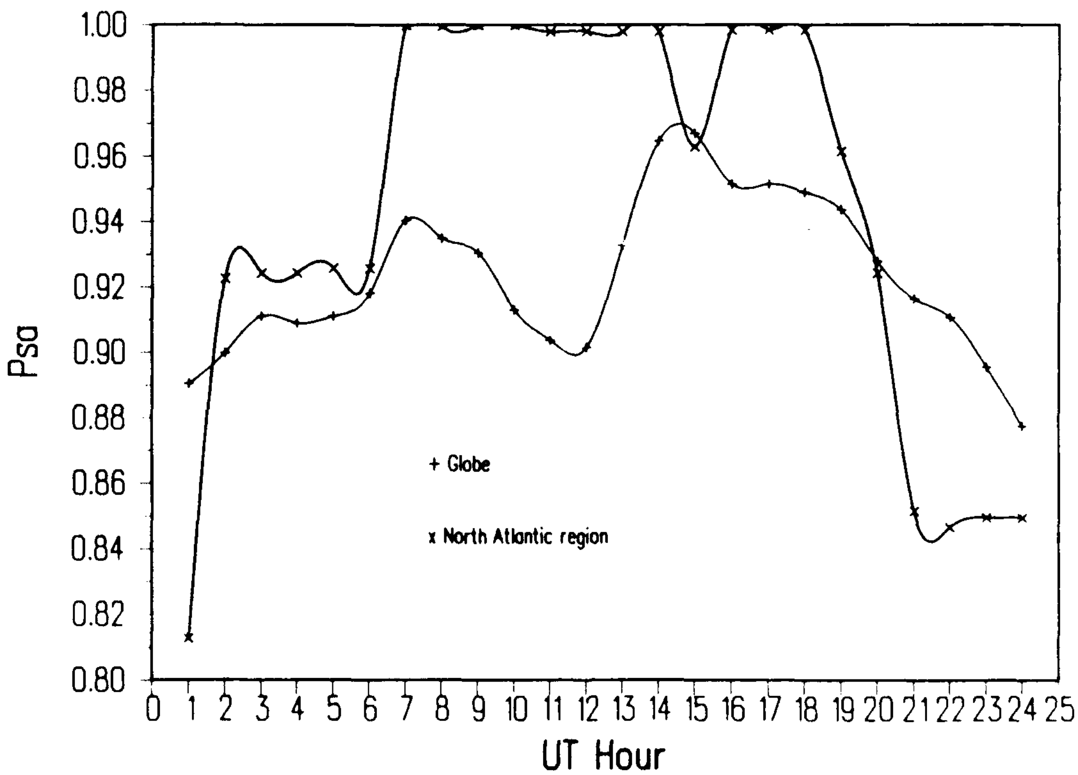

Figure 3.2-3 Comparison of Global and North Atlantic P_{SA} Diurnal Behavior for November using Default PACE Signal Coverage Access Criteria

Figures 3.2-4 and 3.2-5 illustrate the effect on global P_{SA} of Hawaii power reduction during February and August. The February plot shows that a 6 dB reduction in Hawaii power has little effect on P_{SA} during the hours 0100 to about 1500 UT although the P_{SA} difference between Hawaii off-air and on-air is largest during this period (especially 0100 to 0900 UT). After 1500 UT, the P_{SA} diurnal curve for Hawaii at 2.5 kW begins to approach the off-air Hawaii curve. This is apparently due to the fact that, during the hours 0100 to about 0700 UT, signals on westerly paths from Hawaii provide maximum coverage because the paths are generally fully illuminated (up to their SNR range cutoff) and therefore non-modal. Thus, these paths are important contributors to coverage in this region and, when absent, P_{SA} drops substantially. Also, the average daytime signal attenuation rate for westerly paths from Hawaii is about 5 dB/Mm, so that a 6 dB reduction in Hawaii power implies a reduction of approximately one Mm in the path SNR range cutoff, giving rise to little change in coverage. From about 0700-1600 UT, the westerly paths from Hawaii are in darkness giving rise to modal signals so that coverage is less affected by Hawaii's power level. This explains why the 10 kW and 0 kW curves become closer in Fig. 3.2-4. After about 1600 UT, Hawaii signals propagate through a daytime hemisphere to the east (many continue easterly into the nighttime hemisphere) with a much lower average signal attenuation rate than to the west. This leads to a greater

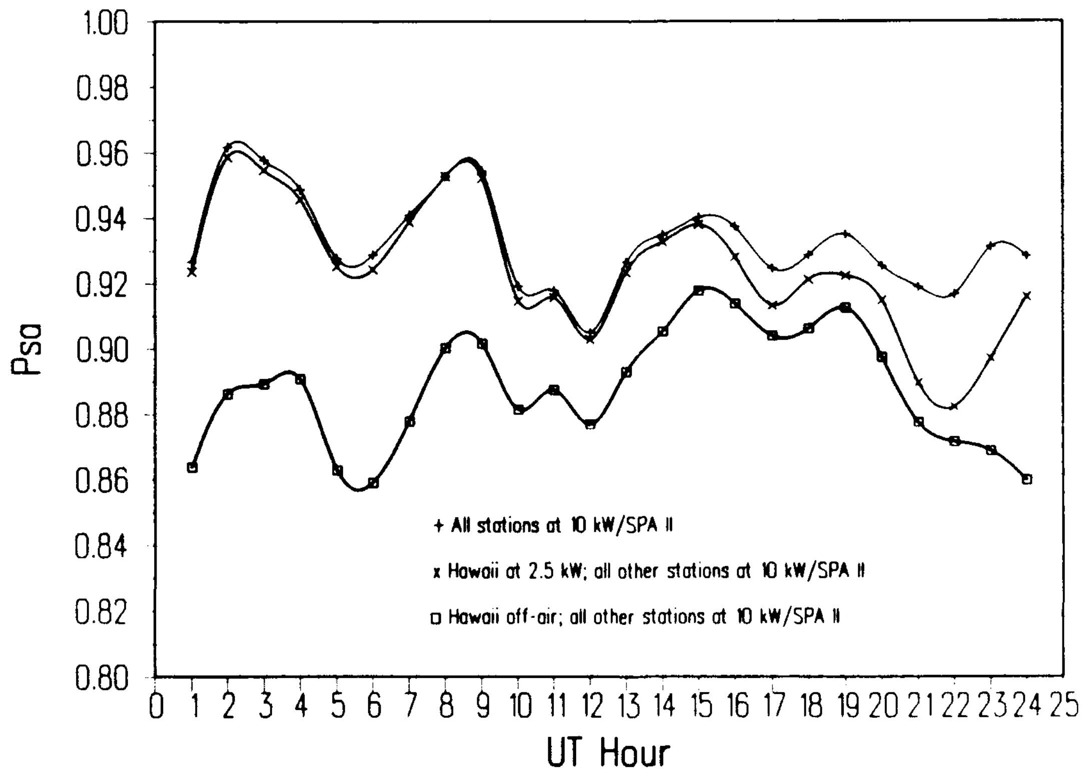

Figure 3.2-4 Effect of Hawaii Power Reduction on Global P_{SA} Diurnal Behavior in February using Default PACE Signal Coverage Access Criteria

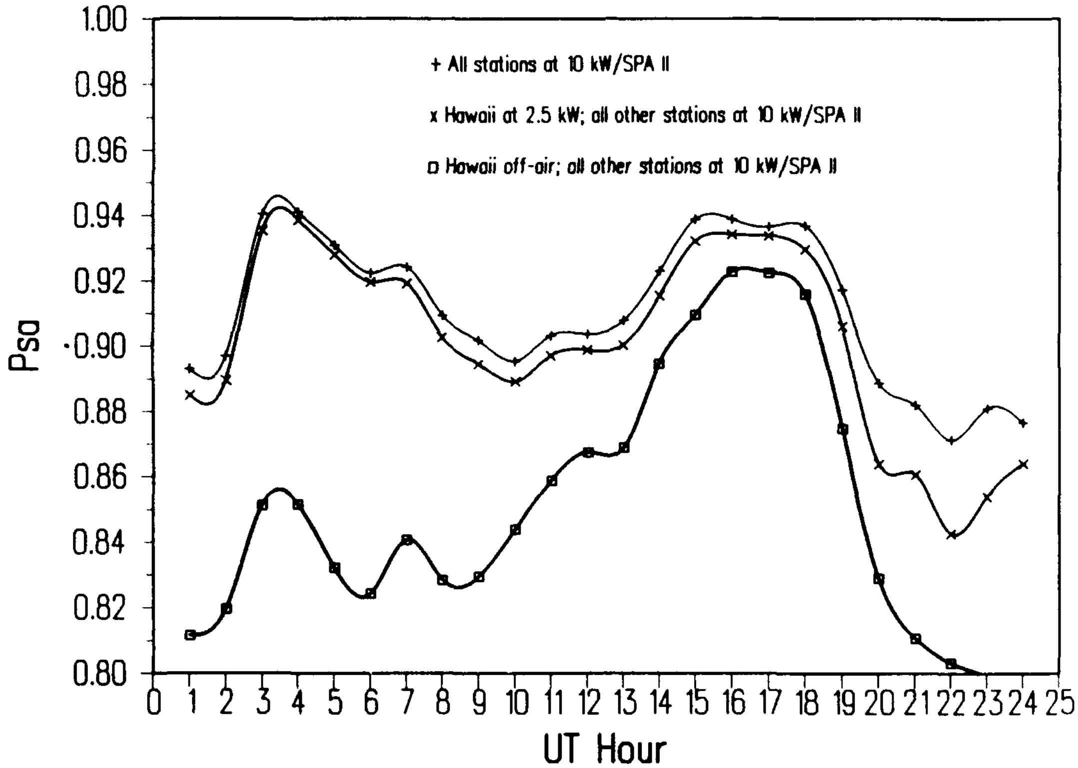

Figure 3.2-5 Effect of Hawaii Power Reduction on Global P_{SA} Diurnal Behavior in August using Default PACE Signal Coverage Access Criteria

dependence on Hawaii power level as reflected in the P_{SA} diurnal curves. Although the underlying P_{SA} diurnal curves are different, most of the same features described in connection with Fig. 3.2-4 appear in Fig. 3.2-5.

Figures 3.2-6 and 3.2-7 also illustrate the effect of Hawaii power reduction at different months and hours, but in these cases, P_{SA} is computed for the cells making up the North Atlantic region, as shown in Fig. 3.2-1. Fig. 3.2-6 shows that, in May, Hawaii power reduction has little effect on P_{SA} — especially from 0700 to 1700 UT, which corresponds to local daytime in the North Atlantic. During the nighttime/transition hours, Hawaii power reduction has a larger effect on P_{SA} because this signal, though somewhat limited in its accessibility to the North Atlantic, plays a role in the rather scarce nighttime coverage in this region. Similar features, though magnified, are seen in the November plot (Fig. 3.2-7). In November, the fraction of a path in daylight decreases (at the same hour), thus increasing the likelihood of modal signals with reduced coverage. As a result, the Hawaii signal assumes more importance during the hours 1100 to 1800 UT in November, when the North Atlantic coverage is sparser than for the corresponding hours in May. During the hours 1900-2300, the SNR cutoff range of the Hawaii signal into the North Atlantic is shorter due to the larger fraction of daylight on the signal paths. Thus, a 6 dB reduction in Hawaii power excludes the signal from

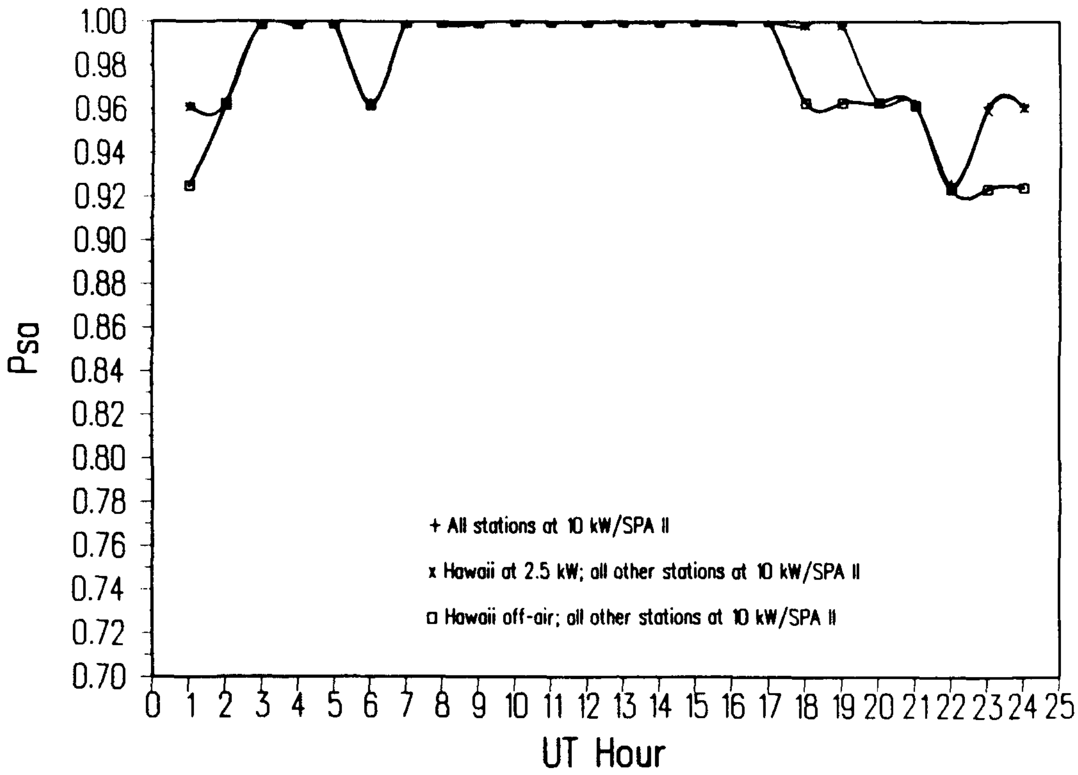

Figure 3.2-6 Effect of Hawaii Power Reduction on North Atlantic P_{SA} Diurnal Behavior in May using Default PACE Signal Coverage Access Criteria

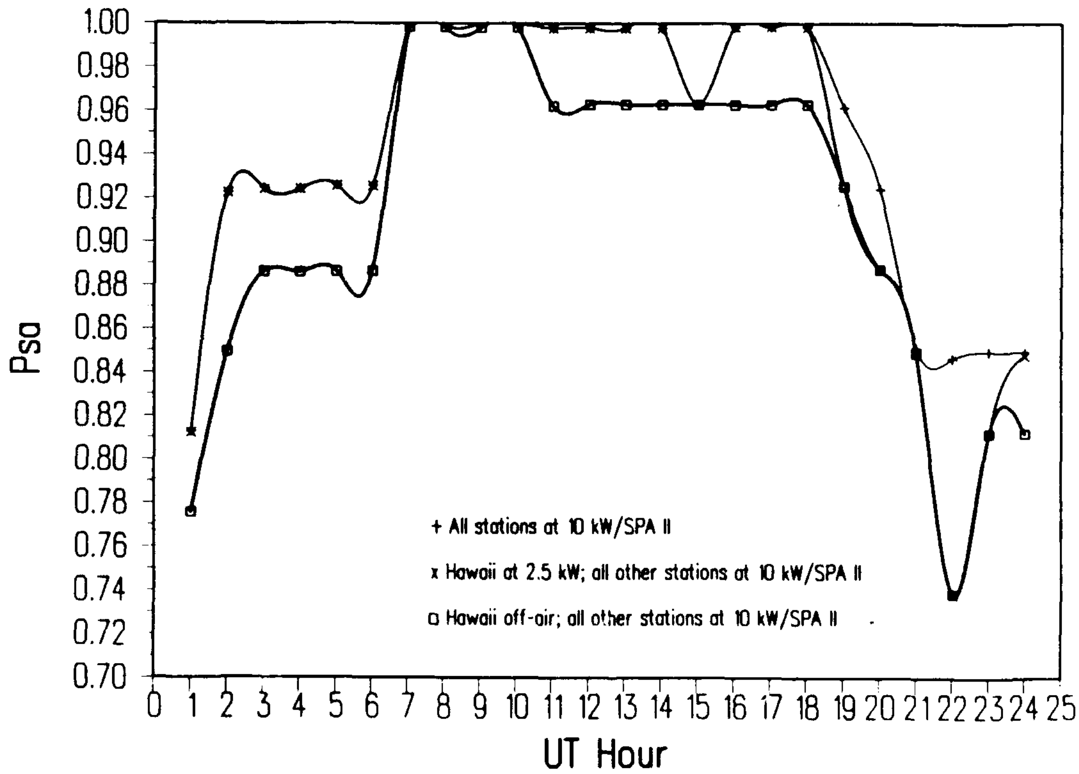

Figure 3.2-7 Effect of Hawaii Power Reduction on North Atlantic P_{SA} Diurnal Behavior in November using Default PACE Signal Coverage Access Criteria

most parts of the North Atlantic. This explains the coincidence of the 2.5 kW and off-air Hawaii P_{SA} curves in Fig. 3.2-7 during these hours. During the hours 2400-0600, the dark portion of the Hawaii-North Atlantic paths becomes larger and the SNR cutoff range increases to more than compensate for a 6 dB reduction in power. Thus, in Fig. 3.2-7, the 10 kW and 2.5 kW Hawaii P_{SA} curves are coincident during the hours 2400-0600 UT.

3.3 SENSITIVITY OF P_{SA} TO SELECTED SIGNAL COVERAGE ACCESS CRITERIA

The analysis of Section 2.3 explored the sensitivity of P_{SA} to the GDOP criterion threshold. In this section, a similar procedure is applied to the SNR and phase deviation criteria. The baseline conditions given in Section 3.1 specify those criteria/thresholds remaining fixed during the P_{SA} threshold sensitivity analysis.

Figure 3.3-1 shows the global P_{SA} diurnal behavior in May for four different SNR thresholds: –10, –20, –30, and –40 dB (100 Hz bandwidth). The P_{SA} diurnal curve parameterized by an SNR threshold of –10 dB is displaced much lower in P_{SA} relative to the other curves. This indicates

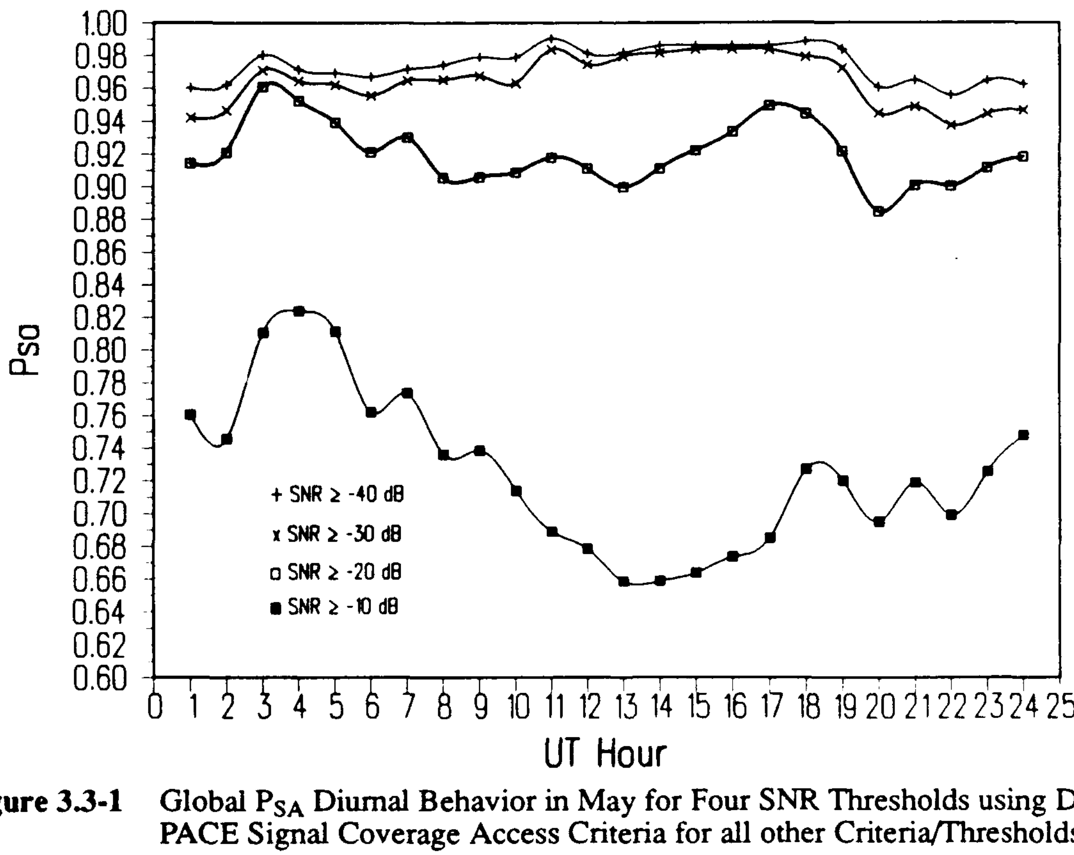

Figure 3.3-1 Global P_{SA} Diurnal Behavior in May for Four SNR Thresholds using Default PACE Signal Coverage Access Criteria for all other Criteria/Thresholds

a substantial fraction of the globe includes signals with SNR between –10 and –20 dB. Fortunately, most Omega receivers on airborne platforms are designed with a minimum signal detection threshold corresponding to an SNR of –20 dB in a 100 Hz bandwidth. Other studies indicate that actual SNR thresholds may be 5 to 10 dB lower (Ref. 1, Appendix B). Fig. 3.3-1 indicates that the P_{SA} diurnal curve for an SNR threshold of –20 dB, although much higher than the curve for –10 dB, is significantly lower (1-8%) than the curve for –30 dB. The exception occurs at about 0300 UT when P_{SA} values for SNR thresholds of –20, –30, and –40 dB are within about 2% of each other. During this time, it is presumed that modal (especially in connection with the Liberia signal) and other non-SNR effects are the principal sources of signal coverage exclusion. Finally, the figure shows little difference in P_{SA} between SNR thresholds of –30 and –40 dB at all hours.

Before exploring the sensitivity of P_{SA} to SPPD threshold, it is necessary to recall that phase deviation threshold and M1DM threshold are coupled as discussed in Section 3.1. Thus, to examine the effect of changing SPPD thresholds, the M1DM criterion is excluded from consideration by choosing the the Dominant Mode selector OFF.

Figure 3.3-2 shows the global P_{SA} diurnal behavior in May for four different phase deviation thresholds: 5, 8, 20, and 25 centicycles. These thresholds sample the probable range of user-selected SPPD thresholds. The least restrictive threshold, 25 cec or 1/4 cycle, can be shown, by means of a simple phasor model, to be the maximum phase error achievable for which M1DM $\geq$ 0 dB. For lower values of M1DM, the phase error is not restricted and can take on values from 0 to 100 cec (or -50 to +50 cec). The 20 cec threshold is the default value which gives a 5 cec margin from the 25 cec threshold. The 8 cec figure corresponds approximately (8.355 cec is a more exact figure) to the maximum phase deviation possible with M1DM fixed at 6 dB. Similarly, the 5 cec value (more precisely, 5.837 cec) is the lower integer bound on the RMS phase deviation, assuming a uniform distribution of IM phase.

The plot in Fig. 3.3-2 shows little difference in diurnal P_{SA} behavior between SPPD thresholds of 20 and 25 cec. Though not shown here, this characteristic also applies to the other three coverage months. The SPPD thresholds of 5 and 8 cec yield distinctly lower diurnal P_{SA} curves, although, even for the 5 cec threshold, P_{SA} never drops below 0.90. It is interesting to note that the downward shift in the P_{SA} curve from an SPPD threshold of 20 cec to 8 cec is about the same as from the 8 cec threshold to the 5 cec threshold. These plots thus give an idea of the relative distribution of SPPD throughout the coverage database.

Figure 3.3-3 compares the P_{SA} diurnal curves in May for the two most restrictive SPPD thresholds (Dominant Mode selector OFF) of Fig. 3.3-2, i.e., 8 and 5 cec, with the P_{SA} diurnal curve

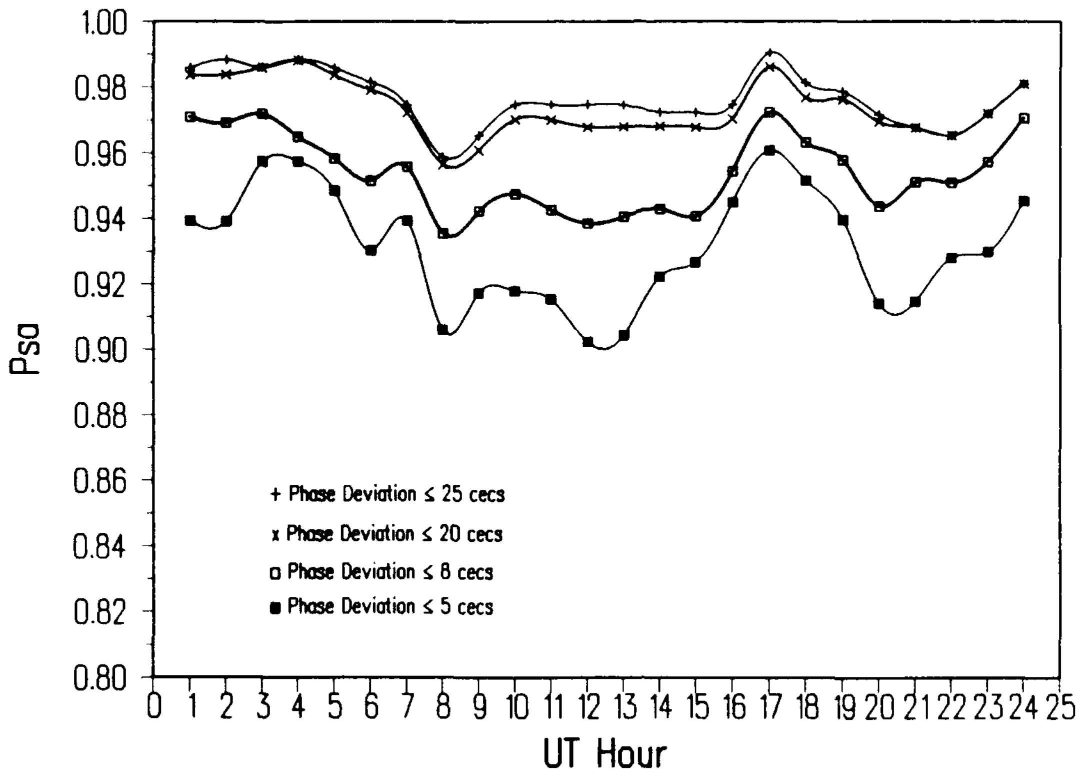

Figure 3.3-2 Global P_{SA} Diurnal Behavior in May for Four SPPD Thresholds using Default PACE Signal Coverage Access Criteria for all other Criteria/Thresholds

for Dominant Mode selector ON. In the latter case, the SPPD threshold is essentially superfluous, since M1DM is restricted to a minimum of 6 dB, corresponding to a maximum phase deviation of about 8 cec. The P_{SA} diurnal curve for M1DM $\geq$ 6 dB tracks the curve for the SPPD threshold of 5 cec fairly well but is lower overall (note especially the period from 1300 through 0200 UT). The closeness of the curves is due to the choice of the SPPD threshold but their difference is due to the additional restriction that M1DM $\geq$ 6 dB imposes: Mode 1 *must* be dominant. This follows because the SPPD criterion only limits phase deviation; it is quite possible that a situation in which a higher mode is dominant may have an SPPD lower than the specified threshold. Thus, invocation of the Mode 1 dominance condition is more restrictive than the SPPD criterion with the analogous deviation threshold.

Figure 3.3-4 illustrates the effect of Hawaii power reduction on diurnal P_{SA} behavior in August with an alternative signal access criterion threshold. In this case the SNR threshold is –30 dB, 10 dB lower than default/baseline case. This plot may be compared with Fig. 3.2-5 which portrays similar information, except that the SNR threshold is at the default value of -20 dB. The plots have similar shape except that the P_{SA} diurnal curves parameterized by the less restrictive –30 dB SNR threshold are shifted upward relative to the –20 dB curve. An important feature of Fig. 3.3-4 is that

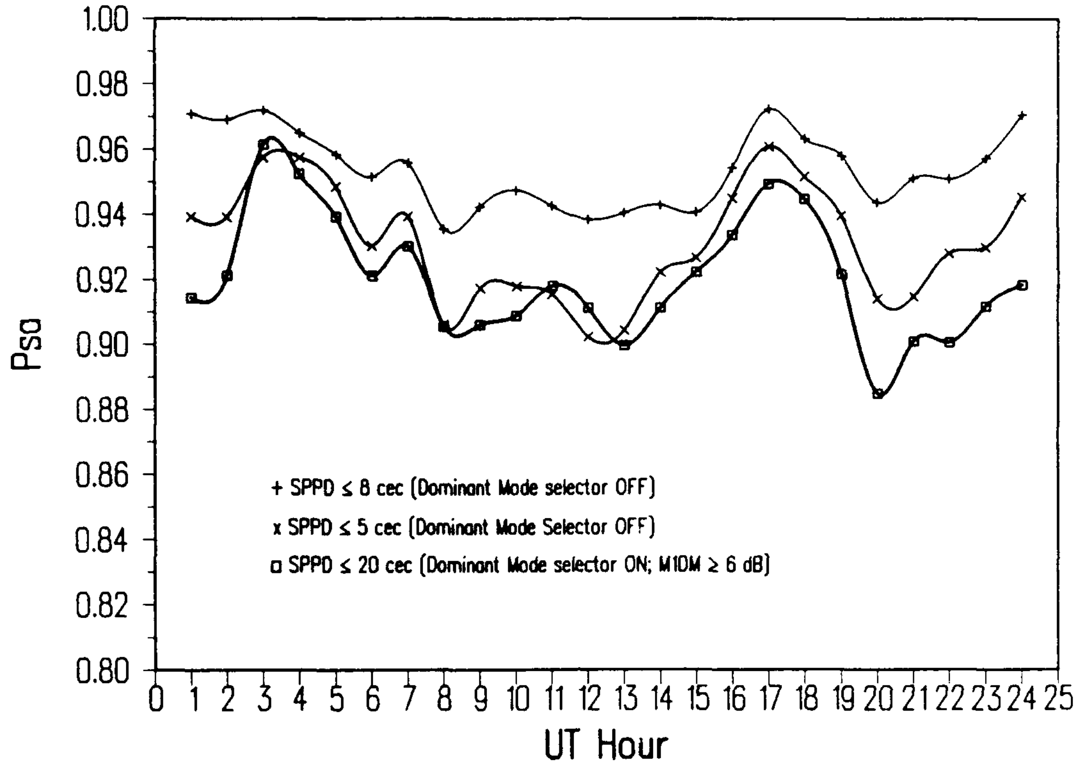

Figure 3.3-3 Global P_{SA} Diurnal Behavior in May for Two SPPD and One M1DM Criteria/ Thresholds using Default Signal Access Criteria/Thresholds unless otherwise specified

the curves for the Hawaii power level at 10 kW and 2.5 kW differ very little. This is supported by the fact that the SNR cutoff for a –30 dB SNR threshold extends to very long ranges, thus providing coverage redundancy. A power reduction of 6 dB on one station, then, leaves generally sufficient coverage and, hence, P_{SA} unchanged. The minimum change in P_{SA} due to Hawaii off-air at 1700 UT for both Figs. 3.3-4 and 3.2-5 occurs because:

- The sunrise terminator lies near the Hawaii station at this hour
- Westerly paths from Hawaii are in darkness and thus generally propagate modal signals whose mode structure does not depend on SNR
- Easterly paths from Hawaii propagate in daytime with higher attenuation rates and thus SNR cutoff ranges are relatively insensitive to changing Hawaii power level
- The daytime hemisphere at this hour has relatively higher redundant signal coverage.

In summary, SPA II P_{SA} results are compared by varying the conditions for the user geographic regional priority and the signal coverage components, while fixing the conditions for all other components. In particular, P_{SA} diurnal behavior for the globe and the North Atlantic is

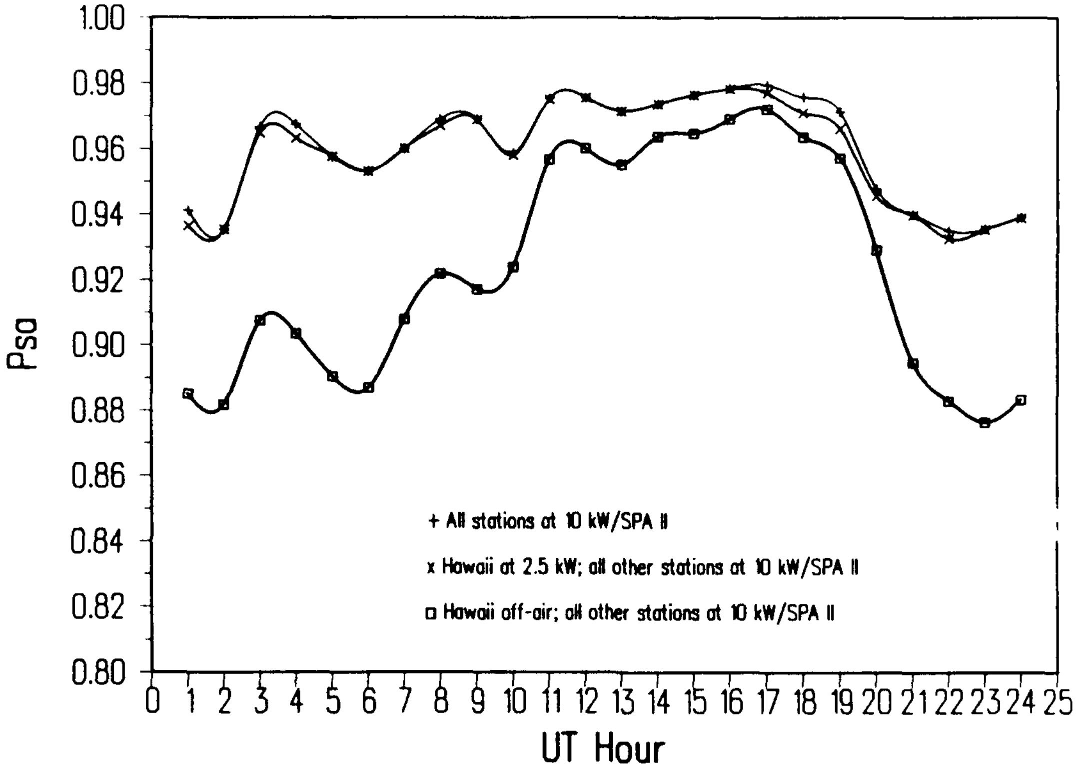

Figure 3.3-4 Effect of Hawaii Power Reduction on Global P_{SA} Diurnal Behavior in August using Default PACE Signal Coverage Access Criteria except that SNR ≥ -30 dB (100 Hz BW)

compared for two months and for the three Hawaii reduced power configurations. The results suggest that P_{SA} for the North Atlantic is higher than the corresponding global results — especially for local day in the North Atlantic. During nighttime hours, North Atlantic P_{SA} results sometimes yield lower P_{SA} values than the corresponding global results. For the signal coverage component, P_{SA} comparisons are made among various signal-to-noise and short-path phase deviation thresholds. Little P_{SA} difference is found between SNR thresholds of –30 dB and –40 dB, but the corresponding difference between –20 dB and –30 dB is significant. Short-path phase deviation thresholds of 20 cec and 25 cec show little change in P_{SA} (with the Dominant Mode criterion disabled) but P_{SA} results for thresholds of 8 and especially 5 cec are similar to those results in which the Mode 1 dominance margin threshold is 6 dB. The latter case yields somewhat lower overall P_{SA} than that for any of the tested phase deviation criterion thresholds because of the exclusion of higher-order mode dominance.

4. COMPARISONS OF P_{SA} AS INTERPRETED BY OMEGA RECEIVER ALGORITHMS AND PACE

In this chapter, SPA II P_{SA} results are compared with corresponding indices of system availability as experienced by an airborne Omega user whose receiver identifies/deselects unusable signals using conventional algorithms. System availability differs in these two cases because P_{SA} depends critically on signal coverage, i.e., the signals defined to be accessible and usable in a given cell at a given time. Since conventional Omega receiver signal deselection algorithms are largely based on earlier ONSCEN-supplied coverage information, the resulting predicted coverage generally differs from PACE predictions because: (1) the signal parameter calculations have been improved, and (2) the signal coverage access criteria have been revised/supplemented.

In conventional airborne Omega receiver systems, some signal coverage parameters, such as SNR, are derived from real-time measurements or geometrical calculations (e.g., GDOP or PTCA). For these parameters, the important question is the agreement between theoretical signal predictions and real-world receiver signal measurements. In contrast, the modal character of a signal cannot be reliably ascertained by real-time on-board measurements, so that the important question is the comparative accuracy of modal assignment algorithms based on theoretical information. P_{SA}, computed with the use of PACE, utilizes recently derived theoretical information to establish the modal character of a signal, whereas conventional Omega receiver/processors do not have access to such data. As a result, the effective signal coverage and, hence, system availability for such receivers are likely to be different from that computed by PACE.

To make these comparisons, P_{SA} is computed using three alternative generic modal deselection algorithms which are believed to cover the range (from most restrictive to least restrictive) of current receiver implementations. These algorithms specify which modal signals to exclude from coverage for a given time/location; other coverage information is emulated in terms of PACE input/calculations based on presumed receiver signal detection and conditioning characteristics. The P_{SA} results from each of these generic modal deselection algorithms are compared and contrasted with PACE results using baseline conditions.

4.1 EMULATION OF GENERIC MODAL SIGNAL DESELECTION ALGORITHMS

The three types of generic modal signal deselection algorithms defined in this section are listed as follows:

- Type I — One-third/two-thirds rule
- Type II — Conservative implementation
- Type III — Modified conservative implementation.

The emulation of each of these algorithm types is also described in terms of PACE inputs and calculations. The emulation only involves the signal coverage component of the System Availability Model. In all cases, the conditions for the station reliability and user geographic regional components are given as follows:

- PACE default reliability statistics
- Uniform weighting of entire globe.

These two conditions are discussed in Section 3.1.

4.1.1 One-third/Two-thirds Rule

The one-third/two-thirds rule states that if a signal path is modal when the path is fully dark, then the path is also modal when the path is at least one-third dark, where "dark" (at any given path point) means a solar zenith angle of greater than 90 degrees. Application of this rule hinges on the availability of information regarding modal signals on paths which are fully dark. Most of the currently used receiver algorithms are believed to employ digitized versions of the nighttime modal maps, first published for 10.2 and 13.6 kHz in 1983 (Ref. 9). Modal information for signals on mixed paths (part day and part night) was available at relatively few global times in the 1980s (see Chapter 1). The one-third/two-thirds rule was developed in response to a need to extrapolate the modal information on all-night paths to mixed paths. Computational models of VLF signal propagation have improved markedly since the early 1980s. For example, in contrast to earlier models, the coverage database which PACE uses is based on mode conversion calculations at the finite-width terminator and at interfaces between large conductivity changes on signal paths. As a result, P_{SA} results from PACE are likely to differ noticeably from those computed using the one-third/two-thirds rule.

The modal information upon which most current receiver algorithms are based can be approximately emulated with the use of PACE and the following modal access criteria:

i) SPPD ≤ 20 cec
ii) Dominant Mode selector ON (M1DM ≥ 0 dB).

These modal criteria, selected to emulate (as closely as possible) earlier coverage diagrams/ information which current receiver algorithms probably employ, are the same as the SPA I-emulated modal criteria described in Section 2.1.2.

To prepare this modal information for PACE processing, a file is created to specify a "central dark hour*" for each path considered by PACE; i.e., paths from all possible stations (8) to all possible cell centers (444), and each of the four coverage months (February, May, August, and November). Using the above modal criteria with the PACE signal coverage database, a modal assignment (for all-night paths) is determined for each path/month and placed in a modal assignment file.

Using the modal assignment file, PACE is executed with the following signal coverage access criteria:

(1) SNR ≥ −20 dB (100 Hz BW)
(2) a) Path is non-modal according to the modal assignment file, or
    b) More than 2/3 of the path is in day
(3) SP/LP ≥ −99 dB
(4) PTCA ≥ 0°
(5) GDOP ≤ 6.

As before, these criteria are chosen to best emulate the conditions under which the signal coverage data was generated to produce the coverage information upon which current Omega receiver deselection algorithms are based. Except for Criterion (2) (which addresses modal effects), the above criteria are the same as the SPA I-emulated signal coverage access criteria given in Section 2.1-2.

4.1.2 Conservative Implementation

The conservative implementation specifies that if a signal path is modal when the path is fully dark, then the path is modal when any portion of the path is dark. This algorithm generally

*This means the middle hour in a contiguous set of path/night hours, e.g., if the nighttime hours for a given path/month are 01, 02, 03, and 24 UT, the central dark hour is 01 UT.

provides "clean" signals for navigation use, but frequently leads to a shortage (less than 3) of Omega signals. As a result, this implementation yields sparser coverage and thus lower P_{SA} values than PACE (or Type I) since not all paths (which are modal when fully dark) are modal when only partially dark. Information regarding modal signals on paths which are fully dark is obtained from the modal assignment file described in Section 4.1.1.

Using the moc'al assignment file, PACE is executed with the following signal coverage access criteria:

(1) SNR $\geq$ –20 dB (100 Hz BW)

(2) a) Path is non-modal according to the modal assignment file, or

b) Path is fully in day

(3) SP/LP $\geq$ –99 dB

(4) PTCA $\geq$ 0°

(5) GDOP $\leq$ 6.

Except for Criterion (2b), these criteria are the same as those the Type I algorithm described in Section 4.1.1.

4.1.3 Modified Conservative Implementation

The modified conservative implementation specifies that if a signal path (characterized by a transmitting station and receiver location) at a given time is modal when the path is fully dark, then the path is non-modal if:

- The path is not fully dark, and
- Fewer than three other station signals are accessible at the receiver location/ time.

Otherwise, the path is assigned modal. This algorithm is used in Omega receiver/processors to avoid "signal starvation," i.e., wholesale deletion of signals as a result of applying, for example, the conservative implementation (Type II). The underlying assumption in this algorithm is that paths (which are modal when fully dark) which are partially dark are less desirable than other paths, but, if needed, can be used. As in the Type I and Type II algorithms, modal signals on paths which are fully dark are listed in the modal assignment file described in Section 4.1.1.

Using the modal assignment file, PACE is executed with the following signal coverage access criteria:

(1) SNR ≥ -20 dB (100 Hz BW)

(2) a) Path is non-modal according to the modal assignment file, or

b) Following two conditions must hold:

i) Path is not fully dark, and

ii) Fewer than three other station signals are accessible at the receiver location/time

(3) SP/LP ≥ -99 dB

(4) PTCA $\geq 0°$

(5) GDOP ≤ 6.

Except for Criterion (2b), these criteria are the same as those for the Types I and II algorithms. Criterion (2b) introduces a complication to the emulation procedure not encountered in the Types I and II algorithms. This criterion involves determining coverage (greater than two-station signal accessibility) for the *other* station signals using the Type II (conservative implementation) signal coverage access criteria.

To emulate this algorithm by using PACE, the following procedure is applied for a given hour/month/cell:

(1) Check coverage using the Type II signal coverage access criteria for each of the eight stations and the GDOP criterion collectively.

(2) If more than two station signals are accessible (and GDOP is satisfied), then each station signal's accessibility is determined by the Type II signal coverage access criteria.

(3) If fewer than three station signals are accessible (or GDOP is not satisfied in step (2)), then each inaccessible signal/path is checked to determine if

a) the path is partially dark

b) the signal/path is modal according to the modal assignment file.

(4) If steps (3a) and (3b) are both true, then the modal character of the signal/path, established by Criteria (2) and (3) of the Type II signal access criteria, is overridden to become non-modal; otherwise, the accessibility of the signal/path, established by the Type II signal access criteria, remains unchanged.

The modified conservative implementation may not improve coverage/P_{SA} relative to that obtained by the conservative implementation in situations where non-modal criteria for one or more signals are not satisfied.

4.3 COMPARISON OF P_{SA} DIURNAL BEHAVIOR: GENERIC RECEIVER ALGORITHMS AND PACE

The comparison of P_{SA} diurnal behavior among the three types of modal deselection algorithms is given in this section for the months of May and November (other coverage months show intermediate behavior). For reference, P_{SA} diurnal behavior is also presented for the condition under which the signal coverage model component uses the default/baseline signal coverage access criteria. The conditions governing the station reliability and user geographic regional priority model components in the reference case are the same as those used for the three generic algorithms.

Figure 4.3-1 illustrates the P_{SA} diurnal behavior in May for each type of modal deselection algorithm as well as for the reference case. The most noteworthy feature of the plot is the similarity of the P_{SA} behavior for the three generic algorithms. As expected, the Type II (conservative) algorithm yields the lowest P_{SA} of the three algorithms for all hours. However, the actual P_{SA} difference between any pair of algorithms is small, especially from 2400 to 0700 UT and from 1600 to 2000 UT. In most cases, the Type III (modified conservative) algorithm yields the highest P_{SA} with the Type I (one-third/two-thirds rule) algorithm being intermediate. One of the largest separations of the

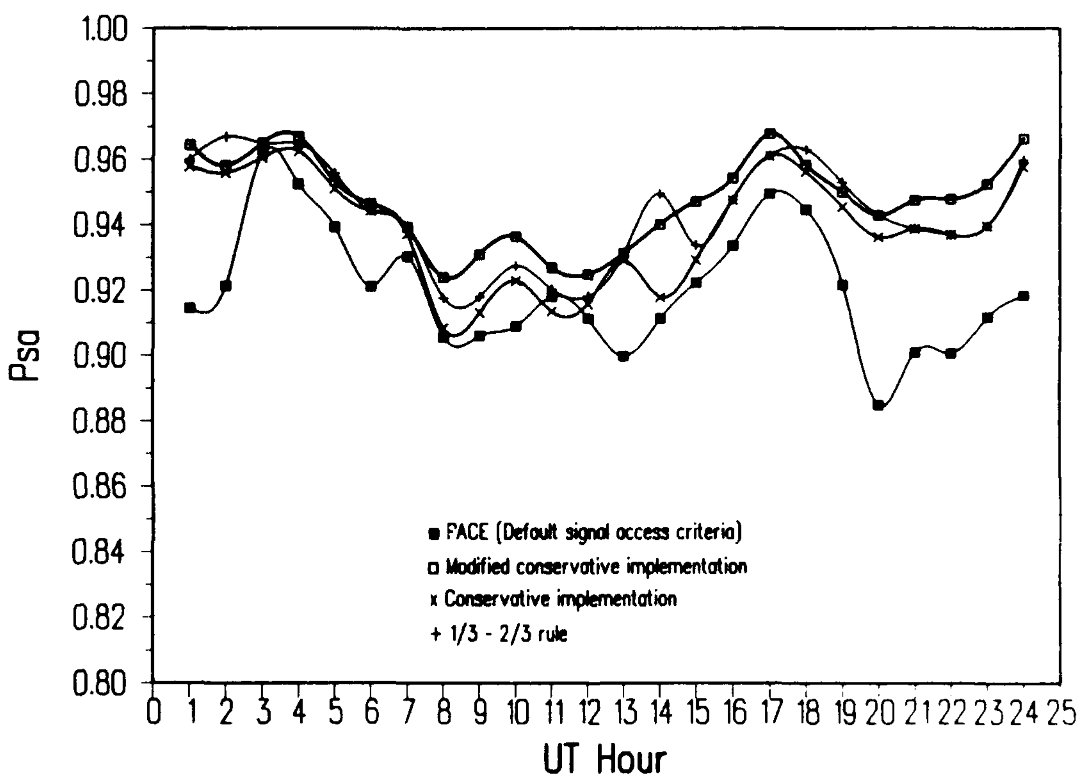

Figure 4.3-1 P_{SA} Diurnal Behavior in May for Three Generic Modal Deselection Algorithms and PACE using Default Signal Coverage Access Criteria

algorithm-parameterized curves (about 2%) occurs at 0800 UT when P_{SA} (for the three algorithms) is at a minimum. Another principal feature of the plot is the significantly lower P_{SA} computed for the default signal access criteria. This is primarily due to the greater restrictions of the default signal access criteria as compared to those criteria on which the three generic types of algorithms are based. The most restrictive of the default criteria (relative to the generic algorithm criteria) is believed to be M1DM $\geq$ 6 dB which imposes Mode 1 dominance and generally limits phase deviations to the range 0-8 cec. Other signal parameters included in the default criteria but not addressed by the generic algorithms are SP/LP and PTCA, whose criteria also serve to limit P_{SA}. Figure 4.3-1 shows that P_{SA} for the default criteria differs relatively little from those for the generic algorithms during the period 0300 to 1800 UT. Outside this period, however, P_{SA} for the default criteria falls as much as 5% below those for the generic algorithms. It is interesting to note that P_{SA} for the default criteria is actually greater than that for the Type II algorithm at 0300 and 1100 UT. This is presumably due to the use of signals, modal on fully dark paths, which are determined (from the PACE database) to be non-modal on partially dark paths.

Figure 4.3-2 illustrates the P_{SA} diurnal behavior in November for each type of modal deselection algorithm as well as for the reference case. The plot shows that the three generic algorithms have more similar P_{SA} behavior for November than for May; in fact, for nearly all hours, the three curves are almost indistinguishable. A second noteworthy feature is that the P_{SA} diurnal curve for the default access criteria is significantly lower (both in an absolute sense and relative to the P_{SA} curves for the generic algorithms) than the corresponding curve in May. Exceptional hours include 1500 UT, where P_{SA} for the default criteria is about the same as that for algorithm Types I and III (and greater than that for Type II) and 0900 UT in which P_{SA} for the Type II algorithm is only slightly higher than that for the default criteria and significantly less than those for the other two algorithms. These results (and data from February and August) indicate that the P_{SA} diurnal behavior associated with the default criteria has a substantially greater month-to-month variation than the variation obtained with the generic algorithms.

In summary, this chapter examines P_{SA} for the signal coverage information (specifically, modal information) available to an airborne user with a conventional Omega receiver. Three generic types of modal deselection algorithms are emulated and the P_{SA} results are compared to those using the default/baseline criteria recommended for use with PACE. As expected the Type II (conservative) algorithm yields the lowest P_{SA} of the three algorithms for all hours. In most cases, the Type III (modified conservative) algorithm yields the highest P_{SA} with the Type I (one-third/two-thirds rule)

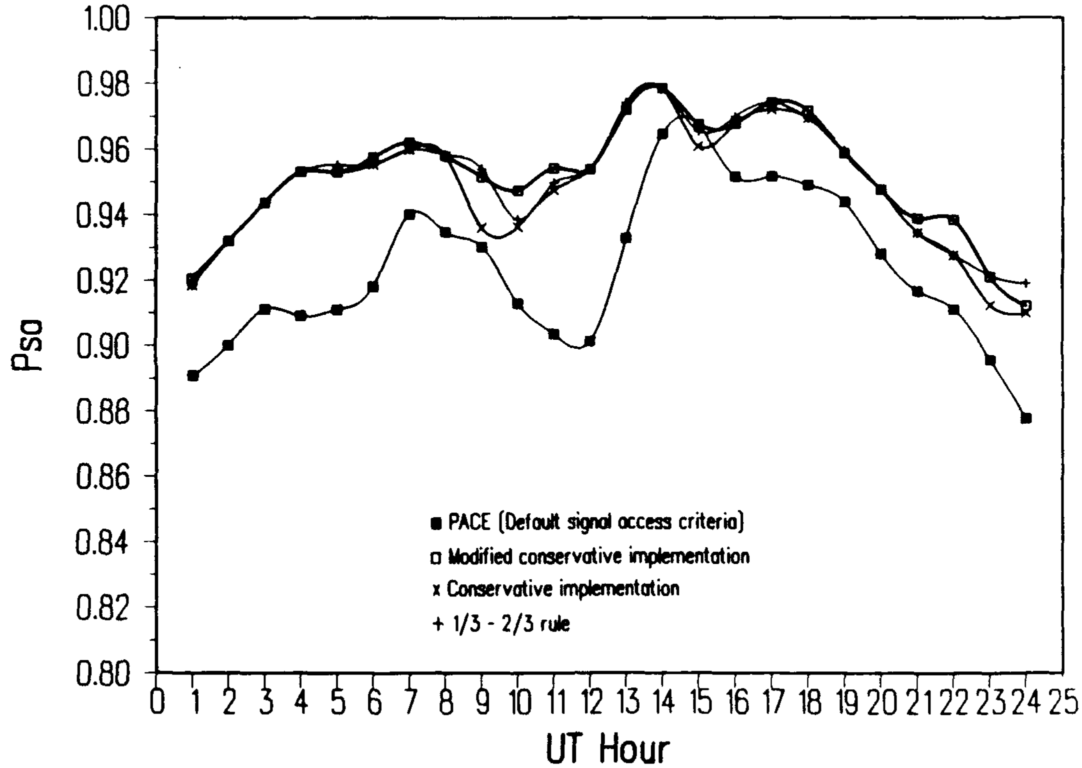

Figure 4.3-2 P_{SA} Diurnal Behavior in November for Three Generic Modal Deselection Algorithms and PACE using Default Signal Coverage Access Criteria

algorithm providing intermediate values. Overall, however, the P_{SA} differences between the three generic algorithms are relatively small. In contrast, the P_{SA} values using the default signal coverage access criteria are nearly always smaller (sometimes, substantially smaller) than P_{SA} obtained for the generic algorithms although the general shape and trends of the P_{SA} diurnal curves are similar.

5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 SUMMARY

The System Availability Model applications considered in this report serve to illustrate the range and scope of the model as applied to the Omega Navigation System. These applications are greatly facilitated with the PACE workstation which implements the standard version of the System Availability Model. As implemented by PACE, the model assumes the Omega receiver is always functional, so that the receiver reliability/availability component of the model is not addressed. Random behavior is confined to the station reliability and user geographic regional priority components in this implementation of the model. The applications addressed in this report are used to compare/examine the system availability as model parameters or inputs to the calculation are varied. Three scenarios, or system configurations, are considered: (1) all stations at 10 kW (full power), (2) Hawaii station at 2.5 kW (all others at full power), and (3) Hawaii off-air (all others at full power).

The signal coverage information contained in the System Availability Model's signal coverage component has been greatly expanded to include virtually all times of interest. The signal coverage information for the SPA II database is obtained from state-of-the-art theoretical models which represent a significant improvement over the models used to generate the earlier databases (including SPA I). The development of this expanded signal coverage database coincided with the development of PACE which is used to compare the system availability index (P_{SA}) computed using default/baseline conditions (known as SPA II results) with P_{SA} computed using earlier coverage information (known as SPA I results). The conditions for the PACE calculations are selected to closely match the earlier (SPA I) coverage conditions so that the resulting comparison reflects only the differences due to the improved signal coverage parameter calculations. The P_{SA} differences are generally found to be small ($\leq$2%) over the rather limited set of hour/month conditions for which SPA I P_{SA} calculations were made. The largest differences (~2-5%) are found at 0600 UT when the Hawaii station is off-air. Comparison of the SPA I/SPA II P_{SA} behavior for a situation in which GDOP is applied/not applied as a collective signal criterion shows that the SPA I and SPA II results differ by about 1%.

SPA II results are compared among several distinct conditions for the user geographic regional component and the signal coverage component. In particular, P_{SA} diurnal behavior for the globe and the North Atlantic is compared for two months and for the three Hawaii reduced power configurations. The results suggest that P_{SA} for the North Atlantic is higher than the corresponding global results — especially for local day in the North Atlantic. At some of the nighttime hours, North Atlantic P_{SA} values are found to be smaller than the corresponding global results. For the signal coverage component, P_{SA} comparisons are made among various signal-to-noise ratio and short-path phase deviation thresholds. Little difference in P_{SA} values is found between SNR thresholds of –30 dB and –40 dB, but the corresponding difference between –20 dB and –30 dB is to be found significant. Short-path phase deviation thresholds of 20 cec and 25 cec show little change in P_{SA} (with the Dominant Mode criterion disabled) but P_{SA} results for thresholds of 8 cec and especially 5 cec are similar to those results in which the Mode 1 dominance margin threshold is 6 dB.

In the final application, P_{SA} is computed for the signal coverage data (specifically, modal information) which would be available to an airborne user with a conventional Omega receiver. Three generic types of modal deselection algorithms are emulated and the P_{SA} results are compared to those using the default/baseline criteria recommended for use with PACE. The P_{SA} differences between the three generic algorithms are found to be relatively small. The P_{SA} diurnal behavior associated with the default signal coverage access criteria, however, is nearly always smaller (sometimes, substantially smaller) than the P_{SA} obtained for the generic algorithms.

5.2 CONCLUSIONS

The diurnal behavior of the system availability index (P_{SA}) is a useful means of comparing/analyzing the effect of changing conditions on system availability. The SPA I evaluation of P_{SA} for Hawaii on-air/off-air, which was limited by the data available to the supporting signal coverage component, shows (when compared with the SPA II results) how P_{SA} results for one or two hours can easily misrepresent P_{SA} over a 24-hour period. The results presented here show that the diurnal variation of P_{SA} is substantial (5-10%) for nominal conditions and must be considered in analyzing system options.

The improved/expanded signal coverage component information has a definite impact on the computed P_{SA} values as indicated by the SPA I/SPA II results comparison. The differences are usually greater when the system is degraded in some way, e.g., with Hawaii off-air. The new 24-hour/4-month/2-frequency signal coverage database also permits a complete space/time analysis of system availability; e.g., the P_{SA} diurnal behavior mentioned above.

In terms of the parameters of the signal coverage component, P_{SA} is found to be highly sensitive to the imposition of the Mode 1 dominance margin criterion (with either a 0 dB or 6 dB threshold), but rather insensitive to phase deviation thresholds above 8 cec; for thresholds below 8 cec, P_{SA} behavior is comparable to that with a 6 dB Mode 1 dominance margin threshold. P_{SA} is also quite sensitive to SNR thresholds greater than -20 dB, but insensitive to thresholds less than -30 dB (as speculated in Ref. 1). If current Omega receiver lower-bound SNR thresholds are, in fact, close to –30 dB, then the results presented here suggest that additional receiver sensitivity or higher transmitting station power is not needed, since P_{SA} is increased only marginally.

Global P_{SA} calculations indicate that, for most of a 24-hour period, a power reduction of 6 dB for the Hawaii transmitting station has little effect on P_{SA}. However, Hawaii disestablishment (permanent off-air) is found to have a substantial (5-10%) impact on system availability. In the North Atlantic region Hawaii power reductions have minimal effect during local daytime; significant effects of this power reduction, however, are noted during local transition/nighttime. These results suggest that disestablishment of the Hawaii station would significantly degrade the system, but if only limited maintenance/repairs are required at the station and the North Atlantic is the region of major Omega interest, then the Hawaii repairs should be conducted during local nighttime in Hawaii (local daytime in the North Atlantic).

Finally, the P_{SA} results for the three generic modal deselection algorithms used in conventional Omega receivers are found to differ little over 24 hours, but generally show significantly higher P_{SA} values than those obtained with default/baseline signal coverage conditions. This means that, in effect, the Omega system "looks better" to users of conventional aircraft-based Omega receivers than to the system manager who evaluates the system using baseline conditions. This result could also be used to support the claim that the deselection algorithms used in conventional receivers should be upgraded so that the appropriate signals are excluded from use.

5.3 RECOMMENDATIONS

The methods employed in this report in applying the System Availability Model to operational questions are powerful and quite general. It is recommended that these methods be used to analyze a variety of system options, including permanent power level reductions/increases at one or more stations, alternative station maintenance periods, and station disestablishment. The methods of analysis should be implemented on the PACE workstation, which facilitates user interaction with the System Availability Model input/calculations/output.

In the current version of PACE, the Mode 1 dominance margin has a fixed threshold of 6 dB. The results presented in this report demonstrate the greater sensitivity of system availability to

Mode 1 dominance margin threshold than to the phase deviation threshold. Moreover, the Mode 1 dominance margin threshold can be set to effectively exclude higher-order modes in addition to limiting phase deviation. It is therefore recommended that the Mode 1 dominance margin be implemented as a signal coverage access criterion in PACE with a user-selectable threshold.

As noted above and in Chapter 4, the signal selection/deselection algorithms found in most conventional airborne Omega receivers are based on rather outdated signal coverage information/data. The new 24-hour/4-month/2-frequency signal coverage database provides more accurate predictions of signal parameters in a greatly expanded time domain using a matrix-based spatial format. It is recommended that this information be made available to Omega receiver manufacturers to be used in updating signal selection/deselection algorithms employed in current or next-generation Omega receivers. It is also recommended that a user-oriented version of PACE, perhaps emphasizing coverage, be developed. This envisioned workstation would be an upgraded version of Omega ACCESS (Ref. 10) with a greatly expanded, improved database and a modern user interface.

APPENDIX A
ABBREVIATIONS/ACRONYMS

BW	—	Bandwidth
cec	—	Centicyle(s)
CCIR	—	International Radio Consultative Committee
D	—	Difference between the phases of the mode-sum signal and Mode 1 signal
dB	—	Decibel(s)
GDOP	—	Geometric Dilution of Precision
Hz	—	Hertz
IM	—	Interfering Mode(s)
kHz	—	Kilohertz
km	—	Kilometer(s)
kW	—	Kilowatt
LOP	—	Line-of-Position
MIDM	—	Mode 1 Dominance Margin
Mm	—	Megameter(s)
ONSCEN	—	Omega Navigation System Center (formerly ONSOD)
PACE	—	Performance Assessment and Coverage Evaluation
P_{SA}	—	System Availability Index
PTCA	—	Path/Terminator Crossing Angle
RMS	—	Root Mean Square
SNR	—	Signal-to-Noise Ratio
SP/LP	—	Short-Path-to-Long-Path Ratio
SPPD	—	Short-Path Phase Deviation
SPA I	—	System Performance Assessment: Phase I
SPA II	—	System Performance Assessment: Phase II
SPSNR	—	Short-Path SNR
VLF	—	Very Low Frequency
UT	—	Universal Time

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